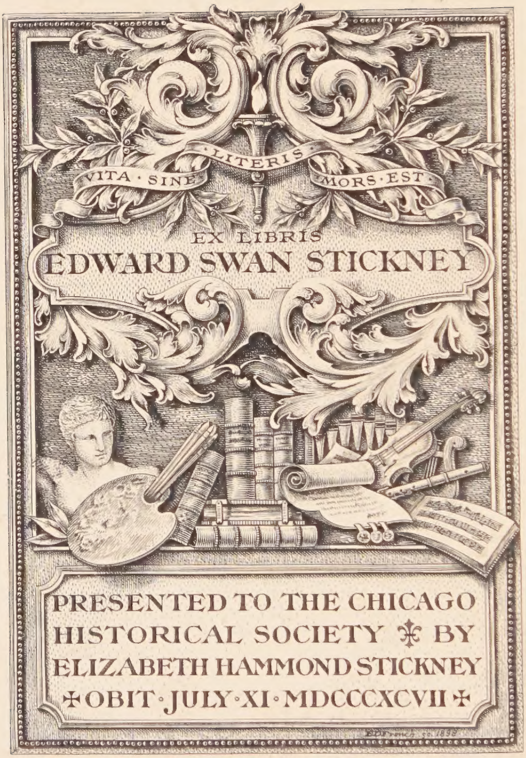
THE ICE AGE IN NORTH AMERICA

G. FREDERICK WRIGHT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Front of Muir Glacier, Alaska, from the southeast corner, looking across the surface and up one of the tributaries. (Photo by Gilbert.) 1890.

THE ICE AGE

IN NORTH AMERICA

AND ITS BEARINGS UPON THE ANTIQUITY OF MAN

BY

G. FREDERICK WRIGHT, D.D., LL.D., F.G.S.A.

Late assistant on the Pennsylvania and United States Geological Surveys
Author of "Logic of Christian Evidences," "Greenland Ice Fields," "Asiatic Russia," etc.

Fifth edition with many new maps and illustrations, enlarged and rewritten to incorporate the facts that bring it up to date, with chapters on Lake Agassiz and the Probable Cause of Glaciation, by Warren Upham, Sc.D., F.G.S.A., late Assistant on the Geological Surveys of New Hampshire, Minnesota, the United States, and Canada.

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1911

TO

ELISHA GRAY

CHEVALIER DE LA LÉGION D'HONNEUR

INVENTOR OF THE HARMONIC TELEGRAPH, THE TELEPHONE

AND THE TELAUTOGRAPH

WHOSE INTELLIGENT INTEREST IN GLACIAL GEOLOGY

AND WHOSE GENEROUS APPRECIATION OF MY WORK

HAVE BEEN A CONSTANT INSPIRATION

THIS VOLUME IS AFFECTIONATELY DEDICATED

PREFACE TO THE FIFTH EDITION.

The twenty years which have elapsed since the publication of the first edition have been exceedingly fruitful in glacial investigations, as will be seen by consulting the bibliography at the end of this volume. Nevertheless, as premised in the preface to the first edition, these later investigations have not seriously affected the main theories adopted twenty years ago, but "pertain mainly to the details of the subject."

In the present revision the new material added is especially abundant only upon a few subjects. Many existing glaciers have been discovered in the Rocky Mountain system in the United States and Canada—a region which was scarcely touched by explorers until the close of the last century. Explorations have also greatly extended our knowledge of Alaskan glaciers while the changes in the Muir Glacier have been so enormous as to be really startling, fully sustaining the theoretical conclusions which I had drawn from my studies of the glacier in 1886. Much new material, also, has accumulated concerning the glaciers of Greenland, Central Asia, and the Antarctic Continent.

As to the extent of the continental glaciers of the Pleistocene period, there has been little additional information since the publication of the first edition. Among the most important additions has been the rectification of the glacial boundary across New Jersey and Pennsylvania, where the "fringe," or "attenuated border," imperfectly apprehended by Lewis and Wright, has been carefully traced by Professor

E. H. Williams from the Atlantic Ocean to Ohio and found to be from twenty to thirty miles south of their terminal moraine.

The facts relating to this border, brought out by Professor Williams, have a most important bearing upon the discussion both of the cause and of the date of the Pleistocene glacial epoch.

There has also been a great accumulation of evidence, collected pretty largely by Mr. Frank Leverett and the geologists of Iowa, Minnesota, Dakota, and Canada, concerning the episodes of the Pleistocene glacial epoch, leading to the division into the Kansan, Illinoisan, Iowan, and Wisconsin periods of advance and retreat. The relative length of time occupied by these episodes is still a most interesting subject of investigation.

The question of the date of the Pleistocene glacial epoch is still a subject of hot discussion, but a great accumulation of facts, relating to post-glacial erosion and sedimentation, are rapidly establishing a very moderate glacial chronology.

Likewise a great accumulation of facts is limiting the theories concerning the cause of glaciation to changes in land elevation and in the direction of oceanic currents. The chapters upon the date and the cause of the epoch have been greatly enlarged and rewritten.

The final chapters upon the discovery of human relics in deposits connected with the Glacial epoch in North America have also been thoroughly revised and enlarged, to take into consideration the more recent discoveries of facts bearing both for and against man's existence here in glacial times.

G. Frederick Wright.

Oberlin, Ohio, *December 22, 1910.*

PREFACE TO FIRST EDITION.

The present treatise is the outcome of special studies upon glacial phenomena begun in the summer of 1874, in the eastern part of Massachusetts, the results of which were published in a communication to the Boston Society of Natural History in December, 1876. These first studies pertained to the origin of the gravel-ridges described in this volume under the name of "kames." Fortunately, in the preparation of that paper, I was favored with an interview with Mr. Clarence King, who then gave me the information referred to in the following pages, concerning the terminal moraine south of New England, which has been so fruitful of suggestion to other investigators as well as to myself. Since that time the subject has never been out of mind, and my summer months have all been devoted, under favorable conditions, to the collection of field notes regarding it, and so it has seemed to others, as well as to myself, appropriate that I should endeavor to bring the facts within the reach of the general public.

After having become, during the four following seasons, familiar with the glacial phenomena over the larger part of New England, I was invited by Professor Lesley to survey, in company with the late Professor H. Carvill Lewis, the boundary of the glaciated area across Pennsyl-

vania (our report constitutes Vol. Z of the Second Geological Survey of that State). The summers of 1882 and 1883 were spent under the auspices of the Western Reserve Historical Society of Cleveland, Ohio (whose secretary, Judge C. C. Baldwin, had the sagacity to recognize, at that early time in the investigations, the historical bearing of the work), in continuing the survey across Ohio, Kentucky, and Indiana (see my report to that society, 1884, and an article in the "American Journal of Science," July, 1883). During the summers of 1884 and 1885 I was employed, as a member of the United States Geological Survey, in tracing the boundary across Illinois, and in reviewing the field in Ohio and western Pennsylvania. The report of this work has not yet been made public, but permission to use the facts has been generously granted by the director of the survey, Major J. W. Powell. The summer of 1886 was spent in Washington Territory, and upon the Muir Glacier in Alaska. The two following seasons were occupied in further exploration of Ohio, Dakota, and other portions of the Northwest. Thus I have personally been over a large part of the field containing the wonderful array of facts of which I am now permitted to write.

In the autumn of 1887 I was invited to give a course of lectures upon the Ice Age in North America before the Lowell Institute in Boston, and in the following year before the Peabody Institute in Baltimore. For the information of the audiences who heard those courses of lectures it is proper to say that the present treatise incorporates all the facts then presented, though in a different form. The volume covers, however, a much wider field than the lectures, and is more ample in its treatment of all the topics.

But it is not to be supposed that a single person can

adequately survey so large a field. The writer is but one of many investigators who have been busily engaged for the past fifteen years (to say nothing of what had been previously accomplished) in collecting facts concerning the Glacial period in this country. My endeavor has been to make the present volume a pretty complete digest of all these investigations, and in carrying out that aim I have had the generous assistance of the great array of careful and eminent observers who have turned their attention to the subject. So far as possible I have, by their permission, given their results in their own language, and with due credit. I hereby take occasion to express my obligations for the help which they have, one and all, so courteously rendered.

The numerous maps accompanying the text have been compiled from the latest data, as indicated in the abundant foot-notes scattered throughout the volume. These render it unnecessary to make here any more specific acknowledgment of authorities.

The volume is committed to the public in the belief that it will meet a widely felt want. The accumulation of facts for the past decade has been so rapid, and from so many sources, that few persons have been able to keep themselves informed of the progress made. And so great has this progress been that we may now safely assume that future discussions will pertain mainly to the details of the subject. We now know, from actual observation, the limits and prominent characteristics of the glaciated area on this continent. The Glacial age of North America is no longer a theory, but a well-defined and established fact.

It will become apparent also that, though the title of the book is the "Ice Age in North America," it is really

a treatise on the whole subject of the Glacial period; for, with the vast field open for investigation on this continent and the amount of attention recently given to its exploration, North America is now by far the most favorable place from which to approach the study of ice-action and ice periods.

The last chapters of the volume treat of man's relation to the Ice age on this continent; and I need not disguise the fact that the bearing of the discoveries upon this question has all along given zest to my investigations. The facts with regard to this subject also are now so far in hand that they can be properly discussed in a treatise designed in part for the general public.

While presenting as fully as is necessary the evidence of man's occupancy of the continent during the great Ice age, and while accepting this as necessitating a considerable extension of man's antiquity as usually estimated, I have not felt called upon in the present discussion to say anything about the method of reconciling this fact with the chronology of the human race supposed to be given in the sacred Scriptures; for I have elsewhere (in my "Studies in Science and Religion," W. F. Draper, Andover, 1882, and "Divine Authority of the Bible," Congregational Publication Society, Boston, 1884) said all that it seems at present necessary for me to say upon this point. I will only remark here that I see no reason why these views should seriously disturb the religious faith of any believer in the inspiration of the Bible. At all events, it is incumbent on us to welcome the truth, from whatever source it may come.

G. Frederick Wright.

Oberlin, Ohio, *April 15, 1889.*

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Errata.

P. 162 lines 21, 22, for "upon a rock shelf" read "at a height of."
P. 304 line 1, for "373" read "573."
P. 306 line 21, for "487" read "800."
P. 630 line 13, after "p. 521" insert foot note "Of the 1st edition."
P. 688 line 20, "auriferou" should be "auriferous."
P. 700 line 18, for "Caliveras" read "Calaveras."

THE ICE AGE IN NORTH AMERICA.

CHAPTER I.

WHAT IS A GLACIER?

To the ordinary man of science, water is a mineral and ice a rock; but to the glacialist both are fluids. The apparent solidity of ice is an illusion due to the dullness of our senses. The reason why its viscous or semi-fluid character remained unsuspected until a comparatively recent period is due to the fact that the ordinary movement of accessible glaciers was so slow that we could not by observation readily note their rate of progress.

The difference between water and other substances is most noticeable in the phenomena connected with solidification and fusing. Lead melts at 612° Fahr. above zero; sulphur, at 226°; water, at 32°; while mercury becomes liquid at 39° below zero, and some other substances at even lower temperatures. Thus, with reference to its fusing-point, water appears toward the middle of the scale. If, like the fabled salamander, man were able to endure intense degrees of heat, he might, very likely, sustain relations to iron similar to those he now sustains to water. He might then bathe with pleasure in a molten flood, and venture on the thin crust of a glowing mass of metal.

The suddenness with which water passes from the solid to the liquid state, and the amount of heat absorbed in the process of fusion, involve many important consequences. Down to the freezing-point water may be made to part with its heat by gradual stages, but in the act of freezing it sud-

denly gives out an enormous amount of heat; on the contrary, when ice melts, a corresponding amount of heat is absorbed in accomplishing the result. To melt a cubic foot of ice requires as much heat as to raise a cubic foot of water 80° C. or 144° Fahr.

For our knowledge of the nature of the movements taking place in glaciers, we are largely indebted to the investigations of Louis Agassiz and Professor Forbes between the years 1840 and 1842, and later to more detailed investigations of Professor Tyndall and other physicists. The mode of measurement with all these investigators was essentially the same. Stakes were driven across a glacier in a line at right angles to the direction of the movement; and, by means of a theodolite, accurate notations were taken, from hour to hour and day to day, of any changes in the relative position of the points where the stakes were driven. The uniform result of these observations was that the line of stakes began immediately to curve slowly down near the middle, showing that the motion on the surface was greater near the middle than on the sides. This curve continued to increase as long as the stakes remained standing.

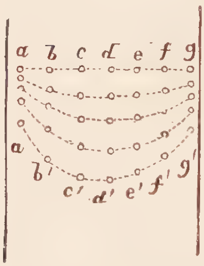

FIG. 1.—The letters *a, b, c, d, e, f, g*, represent stakes driven across the surface of a glacier, at right angles to its line of motion; *a′, b′, c′, d′, e′, f′, g′*, represent these positions at a subsequent stage.

Professor Tyndall's observations show also that the most rapid line of motion on the surface of a glacier is not exactly in the middle; but that, wherever there is a bend in the glacial current, the more rapid movement is uniformly on the convex side of the channel, so that the curve of the line of most rapid motion is more tortuous than that of the main channel. This conforms to the facts concerning the movement of water in a crooked river-bed, and illustrates again the analogy between the movement of ice and that of water.

The most rapid motion observed by Tyndall, in the summer time, in the center of one of the largest of the Alpine

glaciers, was thirty-seven inches per day. Near the sides of the glacier, however, the movement was reduced to two or three inches. The rate of motion during the winter was only about one half that during the summer.

FIG. 2.—The continuous lines define the valley occupied by the glacier. The dotted line with the arrow-heads indicates the line of most rapid motion in the ice, showing its more sinuous course.

A further resemblance of the motion of a glacier to that of a river appears in the fact that the ice near the top moves faster than that near the bottom. At a point in the Mer de Glace where the side of the glacier is exposed, presenting a wall of ice about one hundred and fifty feet in height, Professor Tyndall drove three stakes; one at the summit of the ice, another thirty-five feet from the bottom, and another four feet from the bottom. Upon examination of them, at the end of twenty-four hours, it appeared that, while the top stake had moved forward six inches, the middle one had moved but four and a half inches, and the bottom stake but two and two thirds of an inch.

In all these experiments the influence of friction is clearly visible. The ice of the glacier is retarded by the friction of the sides and bottom of the channel through which it moves, so that the most rapid motion is upon the surface, near the middle, the part farthest removed from this retarding influence.

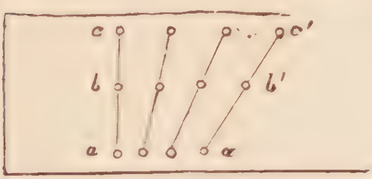

FIG. 3.—*a*, *b*, *c*, are stakes driven in the vertical wall of the side of a glacier; *a'*, *b'*, *c'*, are the points occupied at a subsequent date.

A little attention to this last principle will prepare the mind for crediting the observations which more recently have been reported from the large glaciers in Greenland and Alaska, showing a motion fifteen or twenty times that of the Alpine glaciers. As the cross-section of a glacier is in

creased, the relative influence of friction in retarding the motion is rapidly diminished. The friction on the sides of a glacier two miles wide is no greater than that upon one a quarter of a mile in width, though the cross-section is eight times as large. A cross-section of the Mer de Glace at Les Moulins is estimated to be one hundred and ninety thousand square yards; whereas a cross-section of the Muir Glacier, in Alaska, a mile above its mouth, is upward of one million square yards.

Though observation shows that ice actually moves as if it were a fluid, the scientific imagination is tasked to the utmost to conceive how such motion can be consistent with other manifest qualities of the material; for in many conditions ice seems as brittle as glass and as inelastic as granite. The mystery is probably solved, so far as such questions are ever solved, by attention to the facts already referred to concerning the behavior of ice at its melting-point. When ice passes into water, an immense amount of heat is absorbed in the process, which yet does not produce any effect upon the thermometer. If a hole be bored in the surface of a melting glacier, and a thermometer inserted, it will stand at 32° Fahr. If the same thermometer be inserted in the subglacial stream issuing from the ice front, it will stand at the same point. Yet the absolute difference between the heat contained in the particles of ice, and that contained in the particles of water, is 144° Fahr.—so much heat being occupied in keeping the substance in a liquid form. Ice is also transparent to the rays of heat as it is to the rays of light. Scoresby amused himself, in the arctic latitudes, by making lenses of ice with which to concentrate the sun's rays and set combustible substances on fire.

The fusing-point of ice is also modified by pressure. Under pressure the freezing-point of water may be lowered two or three degrees; but upon the removal of the pressure, the water will instantly become solid. This has been demonstrated in various ways. M. Boussingault, for example, filled a hollow steel cylinder with water, having a bullet loose with-

in it, and plugged the aperture up. He then subjected the cylinder to intense cold till the whole was two or three degrees below the freezing-point of water. But that the water remained liquid was evident from the fact that, upon shaking the cylinder, the bullet inside rattled about as at higher temperatures; while, upon removing the plug so as to relieve the pressure, the whole was instantly converted into solid ice. Various similar experiments have been made in which, upon removal of the plug, the water ejected from the aperture by the expansive power of the cooling water within the cylinder immediately freezes, and forms a projecting column of ice several inches in length. It was at first thought that this projecting column illustrated the plasticity of ice; but it is now pretty certain that it illustrates, rather, the curious effect of pressure upon the freezing-point of water.

The capacity of water at the freezing-point to transform itself, under varying degrees of pressure, from the solid to the liquid state, and *vice versa*, is illustrated by another experiment, ascribed by Professor Tyndall to Mr. Bottomley. A copper wire was looped over a bar of ice about four inches square, and a weight of twelve or thirteen pounds was suspended from it. The pressure under the wire caused the ice in immediate contact with it to melt; but, as the resulting water escaped around the wire, and was relieved from pressure, it immediately froze, and cemented together again the walls of ice above the wire. In half an hour the wire had cut completely through the bar of ice, and yet the whole breach above it was repaired, and the bar was intact.

This capacity of fragments of ice, when near the melting-point, to freeze together when their faces are joined, can be readily observed in a variety of experiments. When two pieces of ice in a basin of warm water are brought together they will immediately adhere. If a cake of ice whose temperature is near the melting-point be placed in a mold and subjected to pressure, the first result is to break it into pieces; but, on continuing the pressure, the particles reunite and freeze together into a shape corresponding to that of the

mold. This capacity of ice, when near the melting-point, to undergo disintegration, and then to become suddenly re-

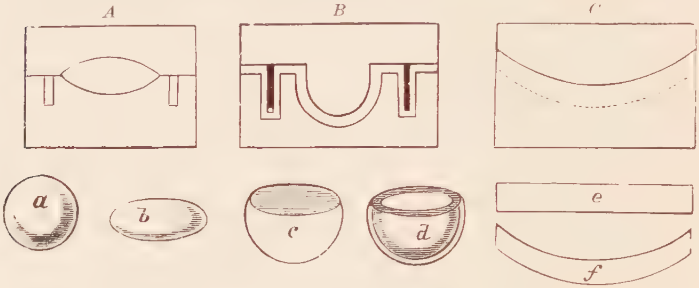

FIG. 4.—*A, B, C,* molds; *a, c, e,* original forms of the ice; *b, d, f,* the forms into which they were molded.

congealed, is probably that by which it simulates in its motion the properties of ordinary fluids, while at the same time retaining other properties connecting it with the most brittle of substances.

It is thought, by Mr. Croll and others, that when heat passes through a stratum of ice, as it is known to do, it involves a process of transference from one particle of ice to another, in which there are successive melting and freezing of the particles in the progress of the heat, and that finally the molecule of ice upon the opposite side, in becoming recongealed, delivers up the unit of heat which had entered the stratum from the other side. But, whatever be the explanation of the process, the facts remain that ice behaves in many respects like a fluid, and, on application of pressure, slowly adjusts itself to its bed or mold in obedience to the force applied, and, if time enough is given, moves wherever a fluid would find its way. Ice is plastic under pressure and brittle under tension.

Snow is one form of ice, and, as every school-boy who makes a snow-ball knows, can by a moderate degree of pressure be made into compact ice. The reason why snow is white, and ice is blue, is that snow is pulverized, while in ice the particles are brought into closer contact, and the inclosed air is expelled, so that the real color of the substance

is brought out. The powder of almost any substance differs in color from the compact mass. Glacial ice is compressed snow, and originates wherever the snow-fall is largely in excess of the melting power of the sun and warm currents of air. Any one can observe how much more compact old snow is than new, and how, under pressure, the lower strata in a snow-bank become in a single season almost like ice. Hence it is easy to see what must be the result where the annual snow-fall is never wholly melted away. In such regions the ice would accumulate without limit, were it not for its semi-fluid character, which permits it to flow off, in lines of least resistance, to lower levels and toward warmer climes.

In structure glacial ice is characterized by both *veins* and *fissures*—two phenomena, which are produced by opposite causes—the first by pressure, and the second by tension.

Glacial ice ordinarily presents a *veined* structure. Instead of being homogeneous, it consists of alternate bands of light-colored and blue ice. These bands do not, however, lie in a horizontal position, but are often vertical. Sometimes they run parallel with the movement of the glacier, and sometimes at right angles to the motion; while, at other times, they are arranged at an angle of forty-five degrees, pointing down the line of motion. From close examination it appears that the veins are always at right angles to the line of greatest pressure.

For example, where two branches of a glacier join, and press together from the sides, longitudinal veins are produced below the point of junction. And again, where ice has descended a declivity, and is advancing upon a less inclined plane, the increased pressure necessary to push the mass along produces bands at right angles to the line of motion; thus demonstrating the connection of veins with pressure. The theory is, that the blue veins in the ice are those from which pressure has expelled the particles of air, thus making it more compact, and giving it its blue color. As already remarked, snow is white because of the abundant particles of air inclosed within it. Under pressure it can be transformed into blue ice, corresponding to the blue veins alluded to

An active glacier is also characterized by *fissures*. Whenever the ice-stream reaches a point where its slope is increased even by a very small amount (a change in inclination of two degrees being sufficient), the ice instead of moving in a continuous stream, forms crevasses across the current, which gradually enlarge at the top, until they present a series of long chasms, very difficult for the explorer to traverse. Where there is considerable irregularity in the bottom, and the increased slope extends for some distance, these crevasses become very complicated, and the surface presents an expanse of towers and domes and pinnacles of ice, often of fantastic appearance; but at the bottom these masses are still joined, and on coming down to a gentler slope they close up again at the surface for their onward march.

FIG. 5.—*c*, *c*, show fissures and seracs where the glacier moves down the steeper portion of its incline; *s*, *s*, show the vertical structure produced by pressure on the gentler slopes.

In addition to the crevasses or fissures, produced by the tension where the ice-stream passes over a steeper incline, a set of marginal fissures extend from the sides of the glacier toward the center, but pointing upward at an angle of about forty-five degrees. These, too, appear to be the result of tension. The motion of the ice in the center, being more rapid than that toward the sides, produces a line of tension, or strain, extending from the center diagonally downward toward the sides at an angle of forty-five degrees. The pressure upon these masses of ice, whose central point is being wheeled downward by the differ

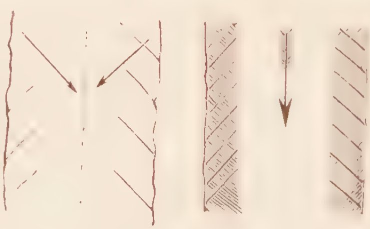

FIG. 6. FIG. 7.
FIGS. 6, 7.—Illustrate the formation of marginal fissures and veins.

ential motion, produces also a veined structure in the masses themselves, at right angles to these marginal fissures.

The surface of a glacier presents many interesting phenomena. When the ice-stream is of sufficient size, the surface is covered with a network of small streams of water, flowing through blue channels of ice sometimes many yards in depth and width. But these are destined eventually to encounter some crevasse, where a circular shaft, or *moulin*, as it is called, is formed, opening a way to a subglacial channel, into which the streams plunge with a loud roar, and the accumulated waters may often be heard rushing onward hundreds of feet below the surface. During the melting of a glacier, also, in the summer season, the surface of the ice is frequently dotted with bowl-shaped depressions, from one or two inches to many feet in depth, and filled with beautiful clear water. The cause of this can not well be conjectured. In Greenland, Nordenskiöld attributed the initial melting to accumulations of meteoric dust which he named kryokonite.

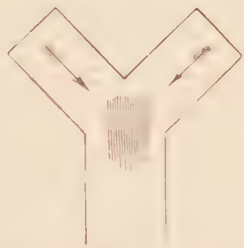

FIG. 8.—Illustrates the formation of veined structure by pressure at the junction of two branches.

Glaciers in mountainous regions are also characterized by *lateral* and *medial* moraines. Where the ice stream passes by a mountain-peak, the falling rocks and the avalanches started by streams of water, form along the edge of the glacier a continuous line of *débris*, which is carried forward by the moving ice, and constitutes what is called a *lateral* moraine. If there be a current of ice on each side of the mountain-peak, two of the lateral moraines will become joined below the mountain, and will form what is called a *medial* moraine, which will be carried along the back of the ice as far as the motion continues. As the ice wastes away toward the front, several medial moraines sometimes coalesce. This, as will be seen, is finely shown in some glaciers of Alaska.

A medial moraine, when of sufficient thickness, protects

the ice underneath it from melting; so that the moraine will often appear to be much larger than it really is: what seems to be a ridge of earthy material being in reality a long ridge of ice, thinly covered with earthy *débris*, sliding down the slanting sides as the ice slowly wastes away. Large blocks of stone in the same manner protect the ice from melting underneath, and are found standing on pedestals of ice, where the general surface has been lowered sometimes several feet. An interesting feature of these blocks is that when the pedestal fails, the block uniformly falls toward the sun, since that is the side on which the melting has proceeded most rapidly.

Fig. 9.—Mode of formation of ice-pillars.

All the material brought down upon the surface of the glacier in the medial moraines is deposited at the front, forming a *terminal* moraine, which will vary in size according to the abundance of material transported by the ice, and in proportion to the length of time during which the front rests at a particular point. But, ordinarily, for a considerable distance this moraine material near the front will rest upon extensive masses of ice which only slowly melt

Fig. 10.—Mer de Glace. The parallel lines in the middle are medial moraines. The main ice-stream on the right pushes the others to the wall, and divides the terminal moraine above *g*.

away. It is largely owing to this that a true terminal moraine is made up of knolls and bowl-shaped depressions called *kettle-holes*, and of short tortuous ridges of bowlders and gravel.

Another result connected with the decay of a glacier is the production of *kames*—this being the Scotch word for sharp, narrow ridges of gravel, corresponding to what are called *osars* in Sweden and *eskers* in Ireland. The trend of these ridges is the same as that of the motion of the glacier, and is at right angles to the terminal moraine. Their formation can be witnessed on a large scale near the front of the Muir Glacier in Alaska. In certain localities a great amount of sand, gravel, and bowlders becomes spread out over the surface of the ice at a considerable elevation. Through some changes in the subglacial drainage a stream wears a long tunnel in the ice underneath this deposit, which at length proceeds so far that the roof caves in, and the earthy *débris* is gradually precipitated to the bottom of the tunnel, thus forming one class of kames. In other places, evidently, water-worn channels in the ice have been silted up by the stream, and then the line of drainage changed, so that, when the supporting walls of ice melted away, another class of kames, with what is called "anticlinal" stratification, is produced.

It should be mentioned also that, after the analogy of a river, a glacier shoves sand and gravel and bowlders underneath it along its bed; from which it can easily be seen that a glacier is a powerful eroding agency, rasping down the surface over which it moves, and by the firm grasp in which it holds the sand, gravel, and bowlders underneath it, producing grooves and scratches and polished surfaces on the rocks below, while these stones themselves will in turn be scratched and polished in a peculiar manner. Wherever the glaciers have receded, so that their bed can be examined, these phenomena, which we reason from the nature of the case must have been produced, are found actually to occur, and a terminal moraine is sure to contain many pebbles and

bowlders bearing marks of the peculiar attrition to which they have been subjected in their motion underneath the ice. The rocks brought along upon the surface of the glacier of course are not thus striated, and ordinarily the mate-

FIG. 11.—Glacial scorings (after Agassiz).

rial of the kames has been so much rolled by water that if the pebbles ever were scratched, the marks have been erased.

With this brief account of the physical characteristics of ice, and of the effects produced by its movement in a glacier, we are prepared to enter more understandingly upon a survey of the actual facts relating to the past and present extent of the ice-fields over the northern part of North America. Reserving the discussion of theories concerning the cause and date of the glacial period to the latter part of the treatise, we will first consider the facts concerning the glaciers still existing in America, and then briefly, by way of comparison, those concerning glaciers in other portions of the world; after which we will present in considerable detail the more recent discoveries concerning the extension and work of the great American ice-sheet during the so-called Glacial period.

PLATE I.—Sperry Glacier, Montana. Looking southward toward its source on Gunsight Peak (9,250 feet). Mary Baker Lake (altitude, 6,500 feet). (Photo by Sperry.)

CHAPTER II.

GLACIERS ON THE PACIFIC COAST.

NOTWITHSTANDING the great height of the Rocky Mountains, they are, in the southern part, devoid of living glaciers. This lack is doubtless caused by the dryness of the atmosphere, the winds from the Pacific having already, before reaching the interior, yielded their moisture to the solicitations of the lofty peaks of the Sierra Nevada and the Cascade Range. Still, a few small glaciers are found among the summits of the Wind River Mountains of Wyoming, and near the sources of Flathead River in Montana. Farther north, however, near the Canadian boundary, glaciers begin to appear in increasing number and size. The broad picturesque summits of the Rocky Mountains forming the continental divide between the head-waters of the Flathead River in Montana and those of the Belly, a branch of the Saskatchewan, in Canada, support innumerable glaciers of small size and many that compare well with those of the Alps. More than forty are found between Lake McDonald and the Canadian boundary. Of these the Sperry and Chaney glaciers are most conspicuous. Avalanche Lake, surrounded by glacier-covered peaks, is one of the most picturesque localities on the continent.

In the Canadian Rockies and in the Selkirk Mountains, north of the line, in Alberta and British Columbia, glaciers increase in numbers and size as higher latitudes are reached. Of these the Victoria, the Wenkchemna, the Yoho, the Illecillewaet and the Asulkan are so near stations on the Canadian

Pacific Railroad that they can be easily visited by tourists. The snow-fields of all these are from 9,000 to 10,000 feet above sea-level, but none of the glaciers descend much below 6,000 feet, except the Illecillewaet which reaches the level of 4,800 feet.

FIG. 12.—West end of Samovar Glacier, Alaska.

A wide arid space, of which few who have not traversed the region can have any conception, separates the Rocky Mountains from the Sierra Nevada nearer the Pacific coast. This latter range of mountains is, in some respects, favorably situated for the production of glaciers, since the peaks are lofty, rising in many places upward of 14,000 feet, and there is abundance of snowfall. Ordinarily, however, there is not breadth enough to the summit of the range to furnish adequate snow-fields for the production of first-class glaciers.

The most southern collection of glaciers in the Sierra Nevada is found near the thirty-seventh parallel, a little east of the Yosemite Valley, in Tuolumne and Mono counties, California. Here is a remarkable cluster of mount-

ain-peaks rising upward of 14,000 feet above the sea, and with breadth enough to support numerous snow-fields and glaciers. No less than sixteen glaciers of small size have been noted among these summits, of which those on Mount Dana, Mount Lyell, and in Parker Creek are the principal. None of them, however, are of great size, being in no case over a mile in length, and none of them descending much below the 11,000-foot line.*

The continuation of the Sierra Nevada Mountains to the north of California is called the Cascade Range, and is largely composed of volcanic rocks. It is on Mount Shasta, in the extreme northern portion of California, that we next find glaciers of any considerable size. But from this point on, glaciers multiply and continue, in ever-increasing glory, through the Coast Range of British Columbia and southern Alaska to the islands of the Aleutian Archipelago.

The glaciers upon Mount Shasta were first described by Mr. Clarence King in 1870. Previous explorers had ascended the mountain upon the southern side, and reported it as free from glaciers, which are all upon the northern side. The most recent and detailed account of the glaciers on this mountain has been furnished by Mr. Gilbert Thompson, of the United States Geological Survey.† According to Thompson, Mount Shasta is a volcanic peak whose altitude above the sea is 14,511 feet. "It stands alone and has no connection with neighboring mountains, none of which within a radius of forty miles attain two thirds its height." The mountain is a conspicuous object to attract attention for over a hundred miles. Five glaciers have been explored upon its northern flank, none of them, however, reaching lower than the 8,000-foot level, and none being more than three miles in length.

The lower part of these glaciers is covered with vast quantities of earthy *débris*, so that it is difficult to tell where the ice-field now ends. It was from these half buried edges

* Russell, "Existing Glaciers," pp. 310–327. † Ibid., pp. 332–334.

of the ice-front on the flanks of Shasta that Mr. King drew the analogies which first solved the problem of the irregular gravel deposits forming the so-called kames and kettle-holes in New England, as above described.* Mr. King gives a thrilling account of how he at one time started such a movement of earth into one of the ice-tunnels, and came near himself falling into the yawning ice-chasm.†

The following are the principal portions of Mr. King's clear and vivid description of the glaciers on the north side of Mount Shasta:

We reached the rim of the cone, and looked down into a deep gorge lying between the secondary crater and the main mass of Shasta, and saw directly beneath us a fine glacier, which started almost at the very crest of the main mountain, flowing toward us, and curving around the circular base of our cone. Its entire length in view was not less than three miles, its width opposite our station about four thousand feet, the surface here and there terribly broken in "cascades," and presenting all the characteristic features of similar glaciers elsewhere. The region of the terminal moraine was more extended than is usual in the Alps. The piles of rubbish superimposed upon the end of the ice indicated a much greater thickness of the glacier in former days. After finishing our observations upon the side crater, and spending a night upon the sharp edge of its rim, on the following morning we climbed over the divide to the main cone, and up the extreme summit of Shasta. . . . From the crest I walked out to the northern edge of a prominent spur, and looked down upon the system of three considerable glaciers, the largest about four and a half miles in length,‡ and two to three miles wide. On the next day we descended upon the south side of the cone, following the ordinary track by which earlier parties have made the climb. From the moment we left the summit we encountered

* Russell, "Existing Glaciers," p. 11.

† "Proceedings of the Boston Society of Natural History," vol. xix, p. 61.

‡ These estimates prove to be somewhat exaggerated. Thompson gives the length of the Whitney Glacier, the longest on the mountain, as only 3,800 yards, less than two miles and a half.

FIG. 13.—Mount Shasta, California. United States Geological Survey (Russell).

less and less snow, and at no part of the journey were able to see a glacier. An east-and-west line divides the mountain into glacier-bearing and non-glacier-bearing halves. The ascent was formerly always made upon the south side, where, as stated, there are no glaciers, and this is why able scientific observers like Professor Whitney and his party should have scaled the mountain without discovering their existence. . . .

Upon reaching the eastern side we found in a deep cañon a considerable glacier, having its origin in a broad *névé* which reaches to the very summit of the peak. The entire angle of this glacier can be hardly less than twenty-eight degrees. It is one series of cascades, the whole front of the ice being crevassed in the most interesting manner. Near the lower end, divided by a boss of lava, it forks into two distinct bodies, one ending in an abrupt rounded face no less than nine hundred feet in height. Below this the other branch extends down the cañon for a mile and a half, covered throughout almost this entire length with loads of stones which are constantly falling in showers from the cañon-walls on either side. Indeed, for a full mile the ice is only visible in occasional spots, where cavities have been melted into its body and loads of stones have fallen in. From an archway under the end a considerable stream flows out, milky, like the water of the Swiss glacier-streams, with suspended sand. Following around the eastern base of Shasta, we made our camps near the upper region of vegetation, where the forest and perpetual snow touch each other. A third glacier, of somewhat greater extent than the one just described, was found upon the northeast slope of the mountain, and upon the north slope one of much greater dimensions. The exploration of this latter proved of very great interest in more ways than one. Receiving the snows of the entire north slope of the cone, it falls in a great field, covering the slope of the mountain for a breadth of about three or four miles, reaching down the cañons between four and five miles, its lower edge dividing into a number of lesser ice-streams which occupy the beds of the cañons. This mass is sufficiently large to partake of the convexity of the cone, and, judging from the depth of the cañons upon the south and southeast slopes of the mountain, the thickness can not be less

PLATE II—Geikie Glacier and Hanging Glacier on Mounts Fox and Dawson, British Columbia. (Photo by Canadian Topographical Survey

than from eighteen to twenty-five hundred feet. It is crevassed in a series of immense chasms, some of them two thousand feet long by thirty and even fifty feet wide. In one or two places the whole surface is broken with concentric systems of fissures, and these are invaded by a set of radial breaks which shatter the ice into a confusion of immense blocks. Snow-bridges similar to those in the Swiss glaciers are the only means of crossing these chasms, and lend a spice of danger to the whole examination. The region of the terminal moraines is quite unlike that of the Alps, a larger portion of the glacier itself being covered by loads of angular *débris*. The whole north face of the mountain is one great body of ice, interrupted by a few sharp lava-ridges which project above its general level. The veins of blue ice, the planes of stratification, were distinctly observed, but neither *moulins* nor regular dirt-bands are present. Numerous streams, however, flow over the surface of the ice, but they happen to pour into crevasses which are at present quite wide.*

From Mount Shasta to the Columbia River the mountains support many glaciers of the third order. Mount Jefferson, Diamond Peak, and the Three Sisters are reported by Mr. Diller and Professor Newberry as containing numerous glaciers, and "as affording the most interesting field for glacial studies in the United States, with the exception of Alaska." The glaciers upon Mount Hood have been more fully explored, and are of great interest, though, owing to the moderate elevation (11,000 feet) and the limited snow-fields, they are small in size. The summit of this mountain is occupied by a volcanic crater about half a mile in diameter. This serves as a fountain out of which there flow three streams of ice extending down the flanks, as glaciers, for a distance of about two miles, their subglacial streams forming the head-waters of the White Sandy, and the Little Sandy Rivers.

In the State of Washington, a short distance north of the Columbia River, the Cascade Mountains culminate in a clus-

* "American Journal of Science," vol. ci, 1871, pp. 158-161.

FIG. 14.—Mount Tacoma, looking westward from an elevation of ten thousand feet over a perpetual snow-field, and the Carbon River Glacier. It is from such positions as this that one gets a true idea of the vast dimensions of mountain-peaks. The graceful cones seen in the view on the opposite page from a distance, become overwhelmingly rough and large when one attempts their ascent. (Both these views are used through the courtesy of Charles S. Fee.)

ter of peaks, with Mount Rainier, or, as it is coming to be called, Tacoma, as the center. This central peak is upward of 14,400 feet in height, and two or three neighboring peaks are upward of 10,000 feet. This great elevation, coupled with the higher latitude and the increasing moisture of the climate, favors the production of a most imposing series of glaciers. Even the passing traveler upon the railroad is made aware of their existence by the milky whiteness of the waters of the Cowlitz, the Nisqually, the Puyallup, and the White River, which are crossed on the way from Portland, Oregon, to Seattle in the State of Washington. All of these streams originate in glaciers far up on the flanks of the mountains to the east and south.

Of this series, that on the north side of Mount Tacoma, at the head of White River Valley, is the largest, and

FIG. 15.—Mount Tacoma, looking eastward toward the summit, from Crater Lake.

reaches down to within 5,000 feet of the sea-level. This glacier is about ten miles long, and, though comparatively narrow in its lower portion, is in places as much as four miles wide. The extreme summit of the mountain has been ascended only by two or three parties, and the task is beset with such difficulties that it is not likely to be ascended often. Above the 9,000-foot level it is wholly enveloped in snow; while just below that limit, and close up to the realm of perpetual ice and snow, flowers make the air fragrant with

their perfume, and the open spaces are gorgeous with their masses of brilliant color.

The following is the description of the glaciers of this mountain cluster, as given by Mr. S. F. Emmons, of the United States Geological Survey, the first to ascend it:

The main White River glacier, the grandest of the whole, pours straight down from the rim of the crater in a northeasterly direction, and pushes its extremity farther out into the valley than any of the others. Its greatest width on the steep slope of the mountain must be four or five miles, narrowing toward its extremity to about a mile and a half; its length can be scarcely less than ten miles. The great eroding power of glacial ice is strikingly illustrated in this glacier, which seems to have cut down and carried away, on the northeastern side of the mountain, fully a third of its mass. The thickness of rock cut away—as shown by the walls on either side—and the isolated peak at the head of the triangular spur . . . may be roughly estimated at somewhat over a mile. Of the thickness of the ice of the glacier I have no data for making estimates, though it may probably be reckoned in thousands of feet.

It has two principal medial moraines, which, where crossed by us, formed little mountain-ridges, having peaks nearly one hundred feet high. The sources of these moraines are cliffs on the steeper mountain-slope, which seem mere black specks in the great white field above; between these are great cascades, and below, immense transverse crevasses, which we had no time or means to visit. The surface water flows in rills and brooks on the lower portion of the glacier, and *moulins* are of frequent occurrence. We visited one double *moulin*, where two brooks poured into two circular wells, each about ten feet in diameter, joined together at the surface but separated below; we could not approach near enough the edge to see the bottom of either, but, as stones thrown in sent back no sound, judged they must be very deep.

This glacier forks near the foot of the steeper mountain-slope, and sends off a branch to the northward, which forms a large stream flowing down to join the main stream fifteen or twenty miles below. Looking down on this from a high, over-

hanging peak, we could see, as it were, under our feet, a little lake of deep, blue water, about an eighth of a mile in diameter, standing in the brown, gravel-covered ice of the end of the glacier. On the back of the rocky spur which divides these two glaciers, a secondary glacier has scooped out a basin-shaped bed, and sends down an ice-stream, having all the characteristics of a true glacier, but its ice disappears several miles above the mouths of the large glaciers on either side. Were nothing known of the movement of glaciers, an instance like this would seem to afford sufficient evidence that such movement exists, and that gravity is the main motive-power. From our northern and southern points we could trace the beds of several large glaciers to the west of us, whose upper and lower portions only were visible, the main body of the ice lying hidden by the high intervening spurs.

Ten large glaciers observed by us, and at least half as many more hidden by the mountain from our view, proceeding thus from an isolated peak, form a most remarkable system, and one worthy of a careful and detailed study.*

Still farther to the north, in the State of Washington, Mount Baker, rising to an elevation of 11,000 feet, is to a limited extent a center for the dispersion of glaciers of small size. The field, however, has been but imperfectly explored.

Northward from the State of Washington the coast is everywhere very rugged, being formed by the lofty peaks of an extension of the Cascade Range; while the thousands of islands which fringe the coast of British Columbia and Alaska are but the partially submerged peaks of an extension of the Coast Range, from which the great glaciers of former times have scraped off nearly all the fertile soil. It is estimated that there are ten thousand islands between the State of Washington and Mount St. Elias, and all the larger of them bear snow-covered summits during the whole year. The water in the narrow channels separating these islands is ordinarily several hundred feet deep, affording, through nearly the whole distance, a protected channel for navigation.

* Quoted by Clarence King, in the "American Journal of Science," vol. ci, pp. 164, 165.

FIG. 16. Map of Southeastern Alaska. The arrow-points mark glaciers.

PLATE III—View of Illecillewaet and Asulkan Glaciers and Snowfields, British Columbia. (Photo by A. O. Wheeler.)

Three great rivers interrupt the mountain barrier of British Columbia facing the Pacific—the Fraser, the Skeena, and the Stickeen—and the interior is penetrated for some distance by innumerable fiords. The Canadian Pacific Railroad follows the course of the Fraser for a long distance, and passes within sight of glaciers of considerable extent, and every fiord receives the drainage of numerous decaying glaciers. But it is not until reaching the Stickeen River, in Alaska, in latitude 57°, that glaciers begin to appear which are both easily accessible and large enough to invite protracted study. The water coming into the sound from the Stickeen River is heavily charged with glacial mud, which spreads itself out over a great expanse. An extensive delta, forming almost the only arable land in southeastern Alaska, has been built up by the deposit at the mouth of this river. The earliest accurate information obtained concerning these glaciers is that gathered by Mr. William P. Blake in 1863. According to him, "there are four large glaciers and several smaller ones visible within a distance of sixty or seventy miles from the mouth" of the river. The second of these larger ones has attracted most attention. This "sweeps grandly out into the valley from an opening between high mountains from a source that is not visible. It ends at the level of the river in an irregular bluff of ice, a mile and a half or two miles in length, and about one hundred and fifty feet high. Two or more terminal moraines protect it from the direct action of the stream. What at first appeared as a range of ordinary hills along the river, proved on landing to be an ancient terminal moraine, crescent-shaped, and covered with a forest. It extends the full length of the front of the glacier." *

This glacier presents many difficulties to explorers. A small party of Russian officers once attempted its exploration, and were never heard from again. Mr. Blake reports that, as usual with receding glaciers, a considerable

* "American Journal of Science," vol. xciv, 1867, pp. 96–101.

FIG. 17.—Norris Glacier, Taku Inlet, Alaska. Showing icebergs that have broken off from the front. Front about one mile wide. (Photograph by Partridge.)

portion of the front as it spreads out in the valley is so covered with bowlders, gravel, and mud that it is difficult to tell where the glacier really ends. But from the valley to the higher land it rises in precipitous, irregular, stair-like blocks, with smooth sides, and so large that it was impossible to surmount them with the ordinary equipment of explorers. The glacier is estimated to be about forty miles long.

Another glacier, upon the opposite side of the river, of which Mr. Blake does not speak, was reported to me by those familiar with the country as coming down to within about two miles of the bank. The Indians are very likely correct in asserting that these two glaciers formerly met, compelling the Stickeen River to find its way to the sea through a vast tunnel. It would then have appeared simply as a subglacial stream of great magnitude.

North of the Stickeen River, glaciers of great size are of increasing frequency, and can be seen to good advantage from the excursion-steamer. The Auk and Patterson glaciers appear first, not far north of Fort Wrangel. On approaching Holkham Bay and Taku Inlet, about latitude 58°, the summer tourist has, in the numerous icebergs encountered, pleasing evidence of the proximity of still greater glaciers coming down to the sea-level. Indeed, the glaciers of Taku Inlet are second only in interest to those of Glacier Bay, hereafter to be described more fully.

In going from Juneau to Chilkat, at the head of Lynn Canal, a distance of about eighty miles, nineteen glaciers of large size are in full sight from the steamer's deck, but none of them come down far enough to break off into the water and give birth to icebergs. The Davidson Glacier, however, comes down just to the water's edge, and has there built up an immense terminal moraine all along its front.

An illustration of the precipitous character of the southeastern coast of Alaska is seen in the fact that it is only thirty-five miles from the head of Lynn Canal to the sources of the Yukon River, which then flows to the north and west for nearly three thousand miles before coming down to the sea-

Fig. 18.—Glacier Station, Selkirk Mountains, British Columbia. (Courtesy of the Canadian Pacific Railroad.)

level. Lieutenant Schwatka reports four glaciers of considerable size in the course of this short portage between Chilkat and Lake Lindeman.* The vast region through which the Yukon flows to the north of these mountains is not known to contain any extensive glaciers. But the ground remains perpetually frozen at a short depth below the surface. Russell reports that in many places cliffs of ice abut upon the border of the Yukon on whose surface is a sufficient depth of soil

FIG. 19.—Davidson Glacier, near Chilkat, Alaska, latitude 59° 45′. The mountains are from five thousand to seven thousand feet high; the gorge about three quarters of a mile wide; the front of the glacier, three miles; the terminal moraine, about two hundred and fifty feet high. (View from two miles distant.)

to support dense evergreen forests. Since the discovery of gold in the region a considerable population has entered, and certain forms of agriculture have begun to flourish.

From Cross Sound, about latitude 58° and longitude 136° west from Greenwich, to the Alaskan Peninsula, the coast is bordered by a most magnificent semicircle of mountains, opening to the south, and extending for more than a thousand miles. Throughout this whole extent, glaciers of large size

* "Science," vol. iii (February 22, 1884), pp. 220–227.

are everywhere to be seen. Elliott estimates that, counting great and small, there can not be less than five thousand glaciers between Dixon's Entrance and the extremity of the Alaskan Peninsula.

The glaciers in the vicinity of Mt. St. Elias are the largest anywhere to be found on the continent. Numerous single glaciers, of which Seward is the largest, come down from the mountain range and, becoming confluent, unite to form the Malaspina glacier. This is a plateau of ice about 1,500 feet in height stretching all along the southern base of the St. Elias range for a distance of fifty miles, and covering an area of about a thousand square miles. In Icy Bay the glacier comes down to sea-level, presenting a solid wall many miles in extent, which is continually breaking off into icebergs of great size. Far out upon the surface large forests occur surrounded by glacial ice. These are supported upon deep beds of gravel and sand which have been carried out by mountain streams whose channels have changed from time to time with the varying conditions of the surface of the ice. Lakes of considerable size are also found upon the surface at an altitude as high as 5,000 feet, with streams flowing between the ice and the mountain side, illustrating, possibly, the origin of many terraces of gravel on the flanks of mountains in the glaciated region of the United States. Such are to be noted on the flanks of both the Green and the Adirondack mountains, deposited originally on the sides of the mass of ice that filled the Champlain Valley.

The glaciers of the St. Elias range are, however, mostly confined to the south side which is exposed to the sea breezes. Schwatka and Hayes who in 1892 made the tour of the range, coming out at Copper River, found the country free from glaciers and the climate so dry that they could comfortably sleep out of doors.

The glaciers about the upper end of Yakutat Bay are of special interest because of the recent changes which have

taken place in them. The narrowing upper portion of the bay which is now bordered by the gravel deposits of the glacial streams pouring out from the southeastern portion of the Malaspina Glacier is called Disenchantment Bay. But above Haenke Island the depression turns at right angles sharply to the south and extends twenty-five miles between mountain ranges forming Russell Fiord. Into this fiord

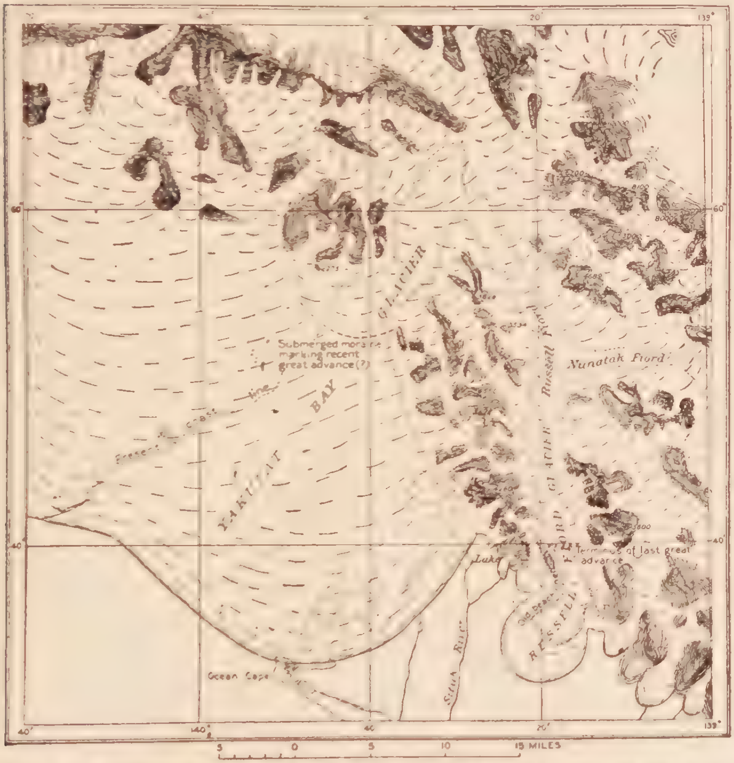

FIG. 20—Map showing hypothetical former extension of glaciers during ice-flood stage, based on observations of the height reached by the glaciers at a number of points. (From U. S. Geological Survey.)

numerous local glaciers descend from both sides. The evidence is clear that at a comparatively recent time, probably as late as the visit of Vancouver near the close of the 18th

century, the Malaspina Glacier, and others near its southeastern border, had advanced so as to completely fill Disenchantment Bay and transform Russell Fiord into a long narrow lake, dammed up by the ice at the mouth of the bay. According to Tarr,* the evidences of this recent advance are abundant in the moraines that were pushed up on the mountain slopes east of Yakutat Bay. But, for some time previous to 1905, a recession had been in progress along the front of all the separate glaciers into which the original confluent glacier had been resolved by the general retreat. Thus he writes:

There is a remarkable change in progress in at least four of the many valley glaciers of the Yakutat Bay region—the Variegated, Haenke, Atrevida, and Marvine. This change is of the nature of a paroxysmal thrust, as a result of which the ice is badly broken, as if a push from behind had been applied with such vigor as to break the rigid resisting ice mass in front. In each case the effect of this thrust is felt from far up the mountain valley well down toward the terminus of the glacier, and in the Haenke and Marvine glaciers to their very end.

In Variegated and Atrevida glaciers the ice has been broken for a distance of five to seven miles: in Marvine glacier the breaking extends fully fifteen miles. The crevassing in all cases extends completely across the valley portion of the glacier and down into the stagnant, or nearly stagnant, moraine-covered margin. In all cases, too, the thrust is accompanied by a forward movement of the margin; and in at least three cases—the Variegated, Haenke, and Atrevida—there has been a distinct thickening of the ice as a result of the forward thrust. . . . Such a remarkable change in the condition of the glaciers as to transform long-stagnant, unbroken, moraine-covered valley glaciers into a labyrinth of crevasses in the short interval of ten months—a phenomenon, so far as known, not elsewhere recorded—calls for a special explanation.

*"United States Geological Survey, Professional Paper" 64, pp. 91-106.

PLATE IV—Forest growing on top of the front of Malaspina Glacier, Alaska. (Photo by Russell.)

Professor Tarr attributes this remarkable advance to the effect of the earthquake which occurred in the region in 1899, six years before. This earthquake, which was sufficient to elevate a portion of the coast forty-seven feet, he supposes to have shaken large quantities of snow down from the more elevated peaks upon the head of the glaciers, and that it took all the intervening six years to make its influence felt at the margin. Thus, as the weather bureau, when the extent of the rainfall at the sources of a great river is known, can predict when the swollen current will reach successive points along the river valley, so the glacialist can foretell, from the snow-fall over the *névé*, when its influence will be felt below through the more resisting medium of the glacial ice.

The suddenness with which this advance began and the vigor with which it went forward afford an interesting commentary upon the prevailing notions entertained concerning the "uniformity of nature's operations," and make it easier for us to credit the vast changes which appear to have taken place in this region since Vancouver's visit in the latter part of the 18th century.

Vancouver's account of the glacial phenomena along this coast is still both instructive and interesting, and in places curious.

Between these points [Pigot and Pakenham] a bay is formed, about a league and a half deep toward the north-northwest, in which were seen several shoals and much ice; the termination of this bay is bounded by a continuation of the above range of lofty mountains. On this second low projecting point, which Mr. Whidbey called "Point Pakenham," the latitude was observed to be 60° 59½′, its longitude 212° 29′. The width of the arm at this station was reduced to two miles, in which were several half-concealed rocks, and much floating ice, through which they pursued their examination, to a point at the distance of three miles along the western shore, which still continued to be compact, extending north 30° east: in this direction they met such innumerable huge bodies of ice, some afloat, others lying on the ground near the shore in ten

FIG. 21—Map of Alaska.

or twelve fathoms water, as rendered their further progress up the branch rash and highly dangerous. This was, however, very fortunately, an object of no moment, since before their return they had obtained a distinct view of its termination, about two leagues farther in the same direction, by a firm and compact body of ice reaching from side to side, and greatly above the level of the sea; behind which extended the continuation of the same range of lofty mountains, whose summits seemed to be higher than any that had yet been seen on the coast.

While at dinner in this situation they frequently heard a very loud, rumbling noise, not unlike loud but distant thunder; similar sounds had often been heard when the party was in the neighborhood of large bodies of ice, but they had not before been able to trace the cause. They now found the noise to originate from immense ponderous fragments of ice, breaking off from the higher parts of the main body, and falling from a very considerable height, which in one instance produced so violent a shock that it was sensibly felt by the whole party, although the ground on which they were was at least two leagues from the spot where the fall of ice had taken place. . . .

The base of this lofty range of mountains [between Elias and Fairweather], now gradually approached the sea-side; and to the southward of Cape Fairweather it may be said to be washed by the ocean; the interruption in the summit of these very elevated mountains, mentioned by Captain Cook, was likewise conspicuously evident to us as we sailed along the coast this day, and looked like a plain composed of a solid mass of ice or frozen snow, inclining gradually toward the low border; which, from the smoothness, uniformity, and clean appearance of its surface, conveyed the idea of extensive waters having once existed beyond the then limits of our view, which had passed over this depressed part of the mountains, until their progress had been stopped by the severity of the climate, and that, by the accumulation of succeeding snow, freezing on this body of ice, a barrier had become formed that had prevented such waters from flowing into the sea. This is not the only place where we had noticed the like appearance; since passing the icy bay mentioned on the 28th

of June, other valleys had been seen strongly resembling this, but none were so extensive, nor was the surface of any of them so clean, most of them appearing to be very dirty. I do not, however, mean to assert that these inclined planes of ice must have been formed by the passing of inland waters thus into the ocean, as the elevation of them, which must be many hundred yards above the level of the sea, and their having been doomed for ages to perpetual frost, operate much against this reasoning; but one is naturally led, on contemplating any phenomenon out of the ordinary course of nature, to form some conjecture, and to hazard some opinion as to its origin, which on the present occasion is rather offered for the purpose of describing its appearance, than accounting for the cause of its existence.*

Westward from Mt. St. Elias the lofty semicircular ranges culminating in Mount Wrangell and Mount McKinley, both of which attain an elevation of 20,000 feet (the former being a live volcano), abound with glaciers beside which those of the Swiss Alps would seem insignificant. While from the flanks of the Chugatch Range immense streams of ice descend to Prince William Sound, and add greatly to the gloomy grandeur of its scenery. Glaciers are also numerous in the Kenai and Alaskan peninsulas as far to the westward as longitude 162°, and one even has been observed upon the island of Unalaska.

Beyond these ranges the broad valleys of the Kuskovim and the Yukon rivers are chiefly characterized by sparsely covered timber areas and tundras in many respects similar to the Arctic litoral of Siberia, where the soil is frozen to a great depth, the heat of the short summer being able to melt scarcely more than a few inches below the surface, sections in many places showing alternate layers of earth and pure ice. In Alaska, however, a few glaciers again appear in the highlands of the far north.

At Eschscholtz Bay, on Kotzebue Sound, in latitude 66°

*"Voyage of Discovery around the World," vol. v, pp. 312-314, 358-360.

15′, Kotzebue discovered in 1818 a cliff of frozen mud and ice "capped by a few feet of soil bearing moss and grass."* Large number of bones of the "mammoth, bison (?), reindeer, moose-deer, musk-ox, and horse, were found" at the base, where they had fallen down from the cliff during the summer thaws. Sir Edward Belcher and Mr. G. B. Seeman afterward visited the same spot and corroborated Kotzebue's account. From their report it was evident that the conditions in northern Alaska are very similar to those in northern Siberia, where so many similar remains of extinct and other animals have been found in the frozen soil. The section described at Eschscholtz Bay seems to be simply the edge of the *tundra* which is so largely represented in the central portions of the Territory. In 1880 Mr. Dall visited the locality and gave a fuller description than had been before given. The conditions are so unique that we reproduce his account:

The ice-cliffs at this point were for a considerable distance double; that is, there was an ice-face exposed near the beach with a small talus in front of it and covered with a coating of soil two or three feet thick, on which luxuriant vegetation was growing. All this might be thirty feet in height. On climbing to the brow of this bank the rise from that brow proved to be broken, hummocky, and full of crevices and holes; in fact, a second talus on a larger scale, ascending to the foot of a second ice-face, above which was a layer of soil one to three feet thick covered with herbage.

The brow of this second bluff we estimated at eighty feet or more above the sea. Thence the land rose slowly and gradually to a rounded ridge, reaching the height of three or four hundred feet only at a distance of several miles from the sea, with its axis in a north-and-south direction, a low valley west from it, the shallow bay at Elephant Point east from it, and its northern end abutting in the cliffs on the southern shore of Eschscholtz Bay. There were no mountains or other high land about this ridge in any direction; all the surface around was lower than the ridge itself.

* See Prestwich's "Geology," vol. ii, p. 463 *et seq.*

About half a mile from the sea, on the highest part of the ridge, perhaps two hundred and fifty feet above high-water mark, at a depth of a foot, we came to a solidly frozen stratum consisting chiefly of bog-moss and vegetable mold, but containing good-sized lumps of clear ice. There seemed no reason to doubt that an extension of the digging would have brought us to solid clear ice such as was visible at the face of the bluff below; that is to say, it appeared that the ridge itself, two miles wide and two hundred and fifty feet high, was chiefly composed of solid ice overlaid with clay and vegetable mold.

The ice in general had a semi-stratified appearance, as if it still retained the horizontal plane in which it originally congealed. The surface was always soiled by dirty water from the earth above. This dirt was, however, merely superficial. The outer inch or two of the ice seemed granular, like compacted hail, and was sometimes whitish. The inside was solid and transparent or slightly yellow-tinged, like peat-water, but never greenish or bluish like glacier-ice. But in many places the ice presented the aspect of immense cakes or fragments irregularly disposed, over which it appeared as if the clay, etc., had been deposited. Small pinnacles of ice ran up into the clay in some places, and, above, holes were seen in the face of the clay bank, where it looked as if a detached fragment of ice had been melted out, leaving its mold in the clay quite perfect.*

After speaking of the frequency with which the bones of the mammoth and buffalo and other animals are found, and of portions of the earth which still has in it the odor of the decaying flesh, Dr. Dall adds:

Dwarf birches, alders seven or eight feet high, with stems three inches in diameter and a luxuriant growth of herbage, including numerous very toothsome berries, grew with the roots less than a foot from perpetual solid ice.

The formation of the surrounding country shows no high land or rocky hills, from which a glacier might have been derived and then covered with *débris* from their sides. The continuity of the mossy surface showed that the ice must be

* "American Journal of Science," vol. cxxi, 1881, pp. 106–109.

quite destitute of motion, and the circumstances appeared to point to one conclusion, that there is here a ridge of solid ice rising several hundred feet above the sea and higher than any of the land about it and older than the mammoth and fossil horse, this ice taking upon itself the functions of a regular stratified rock. The formation, though visited before, has not hitherto been intelligibly described from a geological standpoint. Though many facts may remain to be investigated, and whatever be the conclusions as to its origin and mode of preservation, it certainly remains one of the most wonderful and puzzling geological phenomena in existence.

The same author elsewhere writes that the continuity of this deposit "is broken between Kotzebue Sound and Icy Cape by rocky hills composed chiefly of carboniferous limestones, which bear no glaciers, and do not seem to have been glaciated. The absence of bowlders and erratics over all this area has been noted by Franklin, Beechy, and all others who have explored it." *

During the period of the Russian occupancy of Alaska scarcely anything was added to our knowledge of its glaciers further than what is to be found in the notes of Vancouver's voyage. Even the existence of Glacier Bay, which is to form the subject of the next chapter, was not suspected till a comparatively recent time, and it is not noted on any map drawn previous to 1880. Muir Glacier, which is now the object of greatest interest to the host of summer tourists who crowd the steamers making the round trip from Portland, Oregon, through the waters of southeastern Alaska, was brought to the notice of the outside world by the California gentleman whose name it bears, as late as 1879, when he and Rev. Mr. Young, of the Presbyterian mission at Fort Wrangel, made a voyage of discovery around the archipelago in a dug-out canoe.

* "Bulletin of the Philosophical Society of Washington," vol. vi, p. 33; quoted in Russell, as above, p. 354.

CHAPTER III.

A MONTH WITH THE MUIR GLACIER.

In the summer of 1886 a party of three, consisting of Rev. J. L. Patton, Mr. Prentiss Baldwin, and myself, arranged to visit the Muir Glacier, at the head of Glacier Bay in Alaska, for the purpose of collecting facts concerning its motion, its size, its present general condition, and its probable past history and future career. The present chapter will detail with some minuteness the results of our observation.

On the 4th of August, in company with two Indians for assistants, we were landed by the excursion-steamer on the east side of the inlet, directly in front of the Muir Glacier, with a dug-out canoe as our only means of escape, and two canvas tents as our only shelter. Here we remained a whole month, or until September 2d, while the steamer made a round trip to Portland, Oregon, and returned with another load of freight and tourists. The region is the most desolate imaginable. Indians rarely navigate its upper waters, and it is visited only by the steamer to allow tourists to behold for a few hours the wonderful spectacle of a stream of ice more than a mile in width, and four hundred feet in height, moving onward with irresistible force to meet the equally irresistible waters of a deep tidal inlet. Those who have here, for a few hours only, witnessed the "calving" of icebergs, and heard the detonations preceding and accompanying the falling of the masses from the ice-front, can never forget the scene. Much less can we forget it, who spent a month in the majestic presence of the mighty glacier.

Our facilities for observations were limited by several unfavorable conditions. In the first place, though we were there in the dry season, fifteen of the twenty-nine days were so rainy that it was impossible to stir out of our tents or to see far through the mists. In the second place, the tides were so strong, and the winds at times so violent, that it was hazardous to venture far away with our canoe. In the next place, the surface of the glacier is, in its central portion, so intersected by yawning crevasses that it was entirely out of the question to attempt to cross it. Plans for measurement, different from those made familiar in Professor Tyndall's book, had therefore to be devised.

On the other hand, some things were favorable to obtaining satisfactory results. The fourteen days of fair weather were extremely clear and beautiful, and there are no trees upon the mountains to obstruct one's view or to hinder him in rambling over them.

The specific results as to the movements of the ice, and as to the formation of moraines and kames, are told a little later. Here a few words will be in place concerning the general aspect of the region as we saw it in August.

The mountains on each side of Muir Inlet rise immediately from the water from three thousand to five thousand feet. These we often ascended, and thus were permitted repeatedly to behold one of the most marvelous views anywhere to be found in the world. At that season the level places around our feet upon these summits were carpeted with soft green grass, interspersed with large areas of flowers in full bloom. Here were extensive, gorgeously colored flower-beds, where bluebells, daisies, buttercups, violets, the yellow arnica-flower, and the purple epilobium, were striving for mastery or for recognition. On the northern slopes of slight elevations great masses of snow were preserved in the very midst of these brilliant flower-gardens, and, from their melting, clear little pools of water were on every hand inviting us to drink. The track of the mount-

ain goat, the mountain lion, and of various smaller animals, and the songs of birds, witnessed to the abundance of animal life.

To the south the calm surface of the bay opened outward into Cross Sound, twenty-five miles away. The islands dotting the surface of the smooth water below us seemed but specks, and the grand vista of snow-clad mountains, guarding either side of Chatham Strait, seemed gradually to come to a point on the southern horizon. Westward, toward the Pacific, was the marvelous outline of the southern portion of the St. Elias Alps. The lofty peaks of Crillon (15,900 feet high) and Fairweather (15,500 feet high), about twenty-five miles away, and about the same distance apart, stood as sentinels over the lesser peaks, La Pérouse, Lituya, and their companions, which, anywhere else, would appear to be mountains of the first class, being more than ten thousand feet high, and rising directly from the water's edge. At one time, when on a summit overlooking Glacier Bay, it was our good fortune to see the sun go down behind this mountain-chain. Alternate shadows and golden rays of setting sunlight stretched across the water and climbed the peak on which we stood. The glistering summits of the western mountains were lined with the same glowing colors, while the solemn procession of glaciers on their eastern flanks was gradually fading in the growing darkness, and the more distant mountain-tops in other directions were ceasing to reflect the glow of the western horizon.

In such a setting of grandeur and beauty we gazed upon the full face of the great glacier itself lying at our feet. Below us its diminishing outlet disappeared in the waters of the bay. Distance made the rough places plain, and lent enchantment to the view. Down from the mountains in every direction from the north came the frozen torrents:

Glaciers to the right of us,
Glaciers to the left of us,
Glaciers in front of us,
  Volleyed and thundered—

pouring into a vast amphitheatre, and then uniting their volume, preparatory to their exit through the entrance into Muir Inlet. These numerous local glaciers united to form nine main streams whose individuality could be determined all across the amphitheatre by the long lines of medial moraines which swept around in majestic curves from every quarter, like great railroad embankments in approaching some grand central depot. Such is a faint description of the scene upon which we gazed. Strength and beauty were here united as probably nowhere else in the world. But the shades of night slowly fell upon us, even in that high latitude, and we were compelled to come down closer to the thundering noises of the active glaciers and seek the prosaic quarter of our tents, and to go about the more detailed investigation of the marvelous phenomena before us. The results I will now proceed to give.

The Muir Glacier enters an inlet of the same name at the head of Glacier Bay, in latitude 58° 50′, longitude 136° 40′, west of Greenwich (see Fig. 22). This bay is a body of water about thirty miles long, and from eight to twelve miles wide (but narrowing to about three miles at its upper end), projecting in a northwest direction from the eastern end of Cross Sound. The promontory separating it from the Pacific Ocean is from thirty to forty miles wide, and contains the lofty mountain-peaks of Crillon, Fairweather, Lituya, and La Pérouse, whose heights have already been indicated. To the east, between Glacier Bay and Lynn Canal, is a peninsula, extending considerably south of the mouth of the bay, and occupied by the White Mountains, probably having no peaks exceeding ten thousand feet.

Near the mouth of Glacier Bay is a cluster of low islands named after Commander Beardslee, of the United States Navy. There are twenty five or thirty of these, and they are composed of loose material—evidently glacial *débris*—and are in striking contrast with most of the islands and shores in southeastern Alaska. These, also, like all the other land to the south, are covered with evergreen forests, though

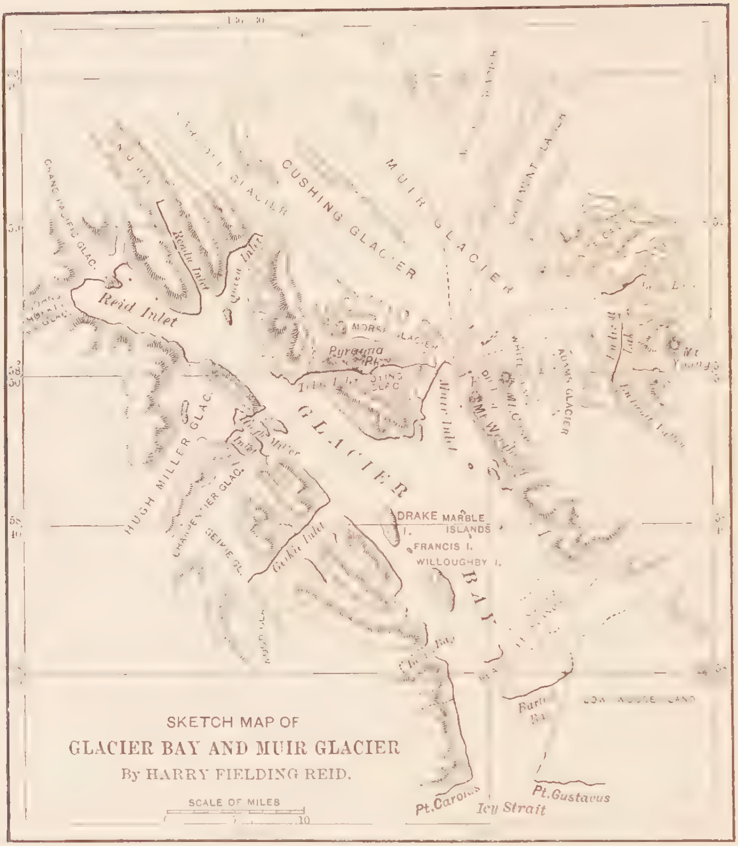

FIG. 22.

the trees are of moderate size; but the islands and shores in the upper part of the bay are entirely devoid of forests. Willoughby Island, near the middle of the bay, is a bare rock, about two miles long and fifteen hundred feet high, showing glacial furrows and polishing from the bottom to the top. Several other smaller islands of similar character in this part of the bay show like signs of having been recently covered with glacial ice.

The upper end of the bay is divided into two inlets of

unequal lengths, the western one being about four miles wide, and extending seven or eight miles (estimated) in the direction of the main axis of the bay to the northwest. The eastern, or Muir Inlet, is a little over three miles wide at its mouth, and extends to the north about the same distance, narrowing, at the upper end, to a little over one mile, where it is interrupted by the front of the Muir Glacier. The real opening between the mountains, however, is here a little over two miles wide, the upper part on the eastern side being occupied with glacial *débris* covering a triangular space between the water and the mountain about one mile wide at the ice-front and coming to a point three miles below, beyond which a perpendicular wall of rock one thousand feet high rises directly from the water. The mountain on the west side of Muir Inlet, between it and the other fork of the bay, is 2,900 feet high. That on the east is 3,150 feet high, rising to about 5,000 feet two or three miles back. The base of these mountains consists of metamorphic slate, whose strata are very much contorted—so much so that it is difficult to ascertain their system of folds. Upon the summits of the mountains on both sides are remnants of blue crystalline limestone preserved in synclinal axes. In the terminal moraine deposited in front of the glacier on its eastern side are numerous bowlders of very pure white marble brought down in medial moraines from mountain valleys several miles to the east. Granitic bowlders are also abundant.

The width of the ice where the glacier breaks through between the mountains is 10,664 feet—a little over two miles. But, as before remarked, the water-front is only about one mile. This front does not form a straight line, but terminates in an angle projecting about a quarter of a mile below the northeast and northwest corners of the inlet. The depth of the water three hundred yards south of the ice-front is (according to the measurement of Captain Hunter, of the steamer Idaho) 516 feet near the middle of the channel; but it shoals rapidly toward the eastern shore. A measurement reported to me by Dr. Jackson, made in July,

FIG. 23—Looking across front of Muir Glacier, Alaska, showing moraine in foreground and ice overriding stratified sand and gravel on opposite shore, 1½ miles distant. 1886

1887, with the prow of the steamer within twenty feet of the ice-front, is one hundred and six fathoms (636 feet), and no bottom. According to my measurements, taken by leveling up on the shore, the height of the ice at the extremity of the projecting angle in the middle of the inlet was 250 feet, and the front was perpendicular. Back a few hundred feet from the projecting point, and along the front nearer the shores, the perpendicular face of the ice was a little over 300 feet. A little farther back, on a line even with the shoulders of the mountains between which the glacier emerges to meet the water, the general height is 408 feet. From here the surface of the glacier rises toward the east and northeast about 100 feet to the mile. On going out in that direction on the ice seven miles (as near as I could estimate), I found myself, by the barometer, 1,050 feet above the bay.

The main body of the glacier occupies a vast amphitheatre, with diameters ranging from thirty to forty miles. This estimate was made from various views obtained from the mountain-summits near its mouth, when points whose distances were known in other directions were in sight. Nine main streams of ice unite to form the grand trunk of the glacier. These branches come from every direction north of the east-and-west line across the mouth of the glacier; and no less than seventeen sub-branches can be seen coming in to join the main streams from the mountains near the rim of the amphitheatre, making twenty-six in all. Numerous rocky eminences also rise above the surface of the ice, like islands from the sea, corresponding to what are called *nunataks* in Greenland. The two of these visited, situated about four miles back from the front, showed that they had been recently covered with ice—their surfaces being smoothed and scored, and glacial *débris* being deposited everywhere upon them. Upon the side from which the ice approached these islands (the *stoss* side) it rose, like breakers on the seashore, several hundred feet higher than it was immediately on the lee side. A short distance farther down on the lee side, however, the ice closes up to its normal height at that

point. In both instances, also, the lee side of these islands seemed to be the beginning of important subglacial streams of water—brooks running into them as into a funnel, and causing a backward movement of ice and moraine material, as where there is an eddy in water. In both these cases, however, the lee sides of these islands were those having greatest exposure to the sunshine. The surface of the ice immediately in front was depressed from one to two hundred feet below the general surface on the lee side.

The ice in the eastern half of the amphitheatre is moving much more slowly than that in the western half. Of this there are several indirect indications: First, the eastern surface is much smoother than the western. There is no difficulty in traversing the glacier for many miles to the east and northeast. Here and there the surface is interrupted by superficial streams of water occupying narrow, shallow channels, running for a short distance and then plunging down into fissures, or, in technical language, *moulins*, to swell the larger current, which may be heard rushing along in its impetuous course far down beneath and out of sight. The ordinary light-colored bands in the ice parallel with its line of motion are everywhere conspicuous, and can be followed on the surface for long distances. When interrupted by crevasses they are seen to penetrate the ice for a depth of many feet, and sometimes to continue on the other side of a crevasse in a different line, as if having suffered a lateral fault. The color of the ice below the surface is an intense blue, and over the eastern portion this color characterized the most of the surface. Numerous holes in the ice, penetrating downward from an inch or two to several feet and filled with water, were encountered all over the eastern portion. Sometimes there was a stone or a little dirt in the bottom of these, but frequently there was apparently nothing whatever in them but the purest of water. In the shallower inclosures on the surface, containing water and a little dirt, worms, about as large around as a small knitting-needle and an inch long, were abundant.

The character and course of the moraines on the eastern half of the glacier also attest its slower motion. There are seven medial moraines east of the north-and-south line, four of which come in to the main stream from the mountains to the southeast (see Fig. 24). Near the rim of the glacial amphitheatre these are long distances, in some cases miles, apart; but, as they approach the mouth of the amphitheatre, they are crowded closer and closer together near its eastern edge, until in the throat itself they are indistinguishably mingled. The three more southern moraines unite some distance above the mouth. One of these contains a large amount of pure marble. This moraine gradually approaches the others on either side until the distance between them disappears, and its marble unites with the other material to form one common medial moraine. The fifth moraine from the south is about 150 yards in width, five miles back from the mouth. It is then certainly as much as five and probably eight miles from the mountains from which the *débris* forming it is derived. All these moraines contain many large blocks of stone, some of which stand above the general mass on pedestals of ice, with a tendency always to fall over in the direction of the sun. One such block was twenty feet square and about the same height, standing on a pedestal of ice three or four feet high. It is the combination of these moraines, after they have been crowded together near the mouth, which forms the deposit now going on at the northeast angle of the inlet just in front of the ice. Of this more will be said in connection with the question of the recedence of the glacier. Similar phenomena, though on a smaller scale, appear near the southwest angle of the amphitheatre.

The dominant streams of ice in the glacier come from the north and the northwest. These unite in the lower portion to form a main current, about one mile in width, which is moving toward the head of the inlet with great relative rapidity. Were not the water in the inlet deep enough to float the surplus ice away, there is no knowing how much farther down the valley the glacier would extend. The

streams of ice from the east and southwest have already spent the most of their force on reaching the head of the inlet; and, were it not for this central ice-stream, a natural equilibrium of forces would be established here independent of the water, and no icebergs would be formed. The surface of this central current of motion is extremely rough, so that it is entirely out of the question to walk far out upon it. On approaching this portion of the glacier from the east the transverse crevasses diagonal to the line of motion increase in number and size until the whole surface is broken up into vast parallelograms, prisms, and towers of ice, separated by yawning and impassable chasms scores and hundreds of feet in depth. Over this part of the ice the moraines are interrupted and drawn out into thinner lines, often appearing merely as patches of *débris* on separate masses of ice. This portion of the ice-current presents a lighter colored appearance than other portions, and the roughened lines of motion can be followed, as far as the eye can reach, through distant openings in the mountains to the north and the northwest.

The comparative rapidity of the motion in this part of the ice is also manifest where it breaks off into the water at the head of the inlet. As already said, the perpendicular front of ice at the water's edge is from 250 to 300 feet in height. From this front there is a constant succession of falls of ice into the water, accompanied by loud reports. Scarcely ten minutes, either day or night, passed during the whole month without our being startled by such reports, and frequently they were like thunder-claps or the booming of cannon at the bombardment of a besieged city, and this, though our camp was two and a half miles below the ice-front. Sometimes this sound accompanied the actual fall of masses of ice from the front, while at other times it was merely from the formation of new crevasses or the enlargement of old ones. Repeatedly I have seen vast columns of ice, extending up to the full height of the front, topple over and fall into the water. How far these columns extended

below the water could not be told accurately, but I have seen bergs floating away which were certainly 500 feet in length. At other times masses would fall from near the summit breaking off part way down, and splashing the spray up to the very top of the ice, at least 250 feet. The total amount of ice thus falling off is enormous. Bergs several hundred feet long and nearly as broad, with a height of from twenty to sixty feet, were numerous and constantly floating out from the inlet. The steamer meets such bergs a hundred miles away. The smaller pieces of ice often so cover the water of the inlet two or three miles below the glacier that it is with great difficulty that a canoe can be pushed through them. One of the bergs measured, was sixty feet above water and about four hundred feet square. The portion above water was somewhat irregular, so that probably a symmetrical form thirty feet in height would have contained it. But even at this rate of calculation the total depth would be two hundred and forty feet. The cubical contents of the berg would then be almost 40,000,000 feet. Occasionally, when the tide and wind were favorable, the inlet would for a few hours be comparatively free from floating ice; at other times it would seem to be full.

The movements of the glacier in its lower portions are probably facilitated by the subglacial streams issuing from the front. There are four of these of considerable size. Two emerge in the inlet itself, and come boiling up, one at each corner of the ice-front, making a perceptible current in the bay. There are also two emerging from under the ice where it passes the shoulders of the mountains forming the throat of the glacier. These spout up, like fountains, two or three feet, and make their way through a channel in the sand and gravel of the terminal moraine for about a mile, and enter the inlet 250 or 300 yards south of the ice-front. These streams are perhaps three feet deep and from twenty to forty feet wide, and the current is very strong, since they fall from 150 to 250 feet in their course of a mile. It is the action of the subglacial streams near the corners of

the inlet which accounts for the more rapid recession of the glacier-front there than at the middle point projecting into the water south of the line joining the east and west corners. It was also noticeable that the falls of ice were much more frequent near these corners, and the main motion of the ice as afterward measured was, not toward the middle point projecting into the inlet, but toward these corners where the subglacial streams emerged below the water.

No small difficulty was encountered in securing direct measurements of the motion; and, as the results may be questioned, I will give the data somewhat fully. As it was impossible to cross the main current of the glacier, we were compelled to take our measurement by triangulation. But even then it seemed at first necessary to plant flags as far out on the ice as it was safe to venture. This was done on the second day of our stay, and a base-line was established on the eastern shore, about a mile above the mouth, and the necessary angles were taken. But, on returning to repeat the observations three or four days afterward, it was found that the ice was melting from the surface so fast that the stakes had fallen, and there were no means at command to make them secure. Besides, they were not far enough out to be of much service. It appeared also that the base-line was on a lateral moraine, which was, very likely, itself in motion. But by this time it had become evident that the masses of ice uniting to compose the main stream of motion retained their features so perfectly from day to day that there was no difficulty in recognizing many of them much farther out than it was possible to plant stakes. Accordingly, another base-line was established on the east side opposite the projecting angle of ice in the inlet. From this position eight recognizable points in different portions of the ice-field were triangulated—the angles being taken with a sextant. Some of the points were triangulated on five different times, at intervals from the 11th of August to the 2d of September. Others were chosen later and triangulated a less number of times.

The base-line finally chosen (marked B on Fig. 24) was at

the foot of the mountain exactly east by the compass from the projecting angle of ice in the inlet. The elevation of the base-line was 408 feet above tide—corresponding to that of the ice-front. The distance of this projecting point of ice (marked C on Fig. 24) from the base-line was 8,534 feet, and it remained very nearly stationary during the whole time—showing that the material breaking off from the ice-

FIG. 24.—Map of Muir Inlet, showing converging moraines, and form of front. Buried forest (A), base of triangulation (B).

front was equal to that pushed along by the forward movement. Satisfactory observations were made upon eight other points numbered and located on Fig. 24.

No. 1 was a pinnacle of ice 1,476 feet north by 30° east from C. The movement from August 14th to August 24th was 1,653 feet east by 15° south. After this date the pinnacle was no longer visible, having disappeared along the wasting line of front between C and the subglacial stream at the northeast corner of the inlet. This was so near the front as to be left out of the ordinary calculations.

No. 2 was a conspicuous pinnacle of ice 2,416 feet north by 16° east of C. Observations were continued upon this from August 11th to September 2d. The total distance moved during that time was 1,417 feet, or about sixty-five feet per day. From August 14th to August 24th the movement was 715 feet, or about seventy-one feet per day. The difference is, however, perhaps due to the neglect to record the hours of the day when the observations were taken. As these observations were wholly independent of each other, their substantial concordance demonstrates that there was no serious error in the observations themselves. The direction of movement of this point of ice was very nearly the same as that of the preceding, namely, east 16° south. This also is toward the subglacial stream emerging from the northeast corner of the inlet.

No. 3 was observed only from August 20th to August 24th. It was situated 3,893 feet north by 62° east of C, and moved 105 feet in a westerly direction, about twenty-six feet per day. The westerly course of this movement probably arose from its being near where the easterly and northeasterly currents joined the main movement.

No. 4 was 5,115 feet north, 42° east of C, and moved from August 20th to August 24th 143 feet in a southeasterly direction, or thirty-six feet per day.

No. 5 was 5,580 feet north, 48° east of C, and moved 289 feet from August 20th to August 24th in a direction east by 39° south, or seventy-two feet per day.

No. 6 was 5,475 feet north, 70° east of C, and moved 232 feet from August 11th to September 2d in a direction south 66° east, or ten feet per day.

No. 7 was 6,903 feet north, 59° east of C, and moved 89 feet between August 14th and August 24th, in a direction south 3° east, about nine feet per day.

No. 8 was 7,507 feet north, 62° east of C, and moved 265 feet from August 14th to August 24th, in direction south 56° east. These last three points lay in one of the moraines on the east side of the line of greatest motion and parallel with it. These moraines are much interrupted in their course by gaps.

It is observable that these points are all east of the center of the main line of most rapid motion, and are tending with varying velocity toward the northeast corner of the inlet, where the powerful subglacial stream emerges from below the water-level. Doubtless, on the other side of the center of motion, and at the same relative distance from the front, the ice would be found tending toward the northwest corner of the inlet, where a similar subglacial stream emerges.

From these observations it would seem to follow that a stream of ice presenting a cross-section of about 5,000,000 square feet (5,000 feet wide by about 1,000 feet deep) is entering the inlet at an average rate of forty feet per day (seventy feet in the center and ten feet near the margin of movement), making about 200,000,000 of cubic feet per day during the month of August. The preceding remarks upon the many indirect evidences of rapid motion render the calculation perfectly credible. What the rate may be at other times of the year there are at present no means of knowing.

The indications that the glacier is receding, and that its volume is diminishing, are indubitable and numerous. The islands of southern Alaska are ordinarily covered with forests of cedar, hemlock, and fir, up to the level of 1,500 or 2,000 feet above tide. But to this rule the shores and islands of the upper part of Glacier Bay are a striking exception. Near the mouth of the bay, forests continue to occur as in other

FIG. 25.—Surface of Muir Glacier, one quarter of a mile back from the front, showing the diagonal crevasses and a medial moraine. The glacier to the left is a tributary; the main glacier is to the right; the mountains in the distance are twenty miles away; the mountain in the middle is surrounded with glacial ice. (Photograph by Partridge.)

parts, only on a diminished scale; but in the upper half of the bay all the shores and islands are perfectly bare of forests, and the rocks retain in the most exposed situations fresh grooves and striæ of glacial origin. It would be impossible for rocks so exposed in such a climate to retain these for an indefinite length of time. Far up on the mountains, also, there are remnants of glacial *débris* in situations such that the material could not have resisted erosive agencies for any great length of time. The triangular-shaped terminal moraine on the eastern side, just below the ice-front, presents some interesting features bearing on the same point. This extends three miles below the glacier, and in its lower portions is thinly covered with vegetation. This covering becomes less and less abundant as the glacier is approached, until, over the last mile, scarcely any plants at all can be found. Apparently this is because there has not been time for vegetation to spread over the upper portion of the moraine since the ice withdrew, for on the mountains close by, where the exposure has been longer, there is a complete matting of grass, flowering plants, and shrubs. Again, in this triangular moraine-covered space there are five distinct transverse ridges, marking as many stages in the recession of the ice-front (see Fig. 24). These moraines of retrocession run parallel with the ice-front on that side, and at about equal distances from each other, each one rising from the water's edge to the foot of the mountain, where they are 408 feet above tide. An inspection of the upper moraine-ridge shows the manner of its formation. This transverse ridge is half a mile below the ice-front, and is still underlaid in some portions with masses of ice ninety feet or more in thickness, which are melting away on their sides and allowing the *débris* covering them to slide down about their bases. Kettle-holes are in all stages of formation along this ridge. The subglacial stream emerging from the southeast corner of the glacier next the mountain rushes along just in the rear of this moraine-ridge, and in front of a similar deposit in process of formation on the very edge of the ice where the medial moraines spoken of termi-

nate. Eventually this stream will break out in the rear of that deposit also, and leave another ridge similar to the one

Fig. 26.—In the foreground on the right is a mass of ice, one half mile in front of the glacier, one hundred or more feet thick, covered with gravel, slowly sliding down to form the rim of a kettle-hole. The mountain back is 3,100 feet high. Near B, Fig. 22.

now slowly settling down into position south of it. This first ridge south of the subglacial stream, with its ice still melting in exposed positions under its covering of gravel, can not be many years old.

Still another sign of the recent date of this whole moraine appears at various places where water-courses, coming down from the mountain, are depositing superficial deltas of *débris* upon the edge of the glacial deposit. These deltas are very limited in extent, though the annual deposition is by no means insignificant. At the southern apex of the moraine, three miles below the ice-front, and but one hundred or two hundred yards from our camp, great quantities of *débris* came tearing down in repeated avalanches during a prolonged season of rain. Twenty-five years would be more than ample for the formation of the cone of *débris* at the foot of this line of avalanches. Thus there can be no reasonable doubt that

during the earlier part of this century the ice filled the inlet several miles farther down than now. And there can be scarcely less doubt that recently the glacier filled the inlet, 2,500 feet above its present level near the front; for the glacial *débris* and striæ are very marked and fresh on both mountains flanking the upper part of the inlet up to that height, and the evidences of an ice movement in the direction of the axis of the bay are not wanting as high as 3,700 feet on the eastern mountain, where I found fresh striæ running north by south, and directly past the summit, which rises 1,000 or 1,500 feet still higher, just to the east.

To this circumstantial evidence may be added what seems to be an irresistible inference from the notes of Vancouver's party in 1794. This party entered Cross Sound in small boats, and penetrated as far as the head of Lynn Canal and Juneau.

The following is the record. We should premise, however, that the point referred to as seven miles from Point Dundas is probably that at the southeastern corner of Glacier Bay, and the "spacious inlet lying in an east-southeast" direction is probably the channel extending toward Chatham Strait. But certainly, no one looking from that point at the present time would speak, as this report does, of this inlet as seeming to be "entirely occupied by one compact sheet of ice as far back as the eye could distinguish." Nor would the observer at the present time say that, to the north and east, the two large open bays formed by the shores of the continent seemed to be "terminated by compact solid mountains of ice rising perpendicular from the water's edge." The ice is now full twenty-five miles away from that point, and the ice-front is not sufficiently prominent to make such an impression as this. It is hence more than probable that, at that time, the ice extended down nearly to the mouth of the bay.

The morning of the 12th [July], though unpleasant, was rather more favorable to their pursuit, which was still greatly

impeded by the ice. From the east point of this branch, which I have called Point Dundas, situated in latitude 58° 21′, longitude 224° 1′, the coast takes an irregular east-northeast direction about seven miles to a point whence this branch of the [Cross] Sound appeared to be very extensive in an east-southeast point of view, and was upward of three leagues across. The party proceeded from Point Dundas to this station, through a channel from two to three miles in width, between the continental shore and an island about seven miles long and three miles broad, lying in a northeast and southwest direction. This spacious inlet presented to our party an arduous task, as the space between the shores on the northern and southern sides seemed to be entirely occupied by one compact sheet of ice as far as the eye could distinguish. . . . To the north and east of this point the shores of the continent form two large open bays, which were terminated by compact solid mountains of ice, rising perpendicularly from the water's edge, and bounded to the north by a continuation of the united lofty frozen mountains that extend eastward from Mount Fairweather. In these bays also were great quantities of broken ice, which, having been put in motion by the springing up of a northerly wind, was drifted to the southward, and, forcing the boats from the northern shore, obliged them to take shelter round the northeast point of the above island. This made Mr. Whidbey apprehensive that the still apparent connected body of ice, from side to side, would at length oblige him to abandon his researches by this route, unless he should find it possible to force a passage through this formidable obstruction.

In attempting this, the party succeeded far beyond their expectations, for they gained an open navigation, and by four in the afternoon arrived at a low and nearly round island about two leagues in circuit, lying from the former island north 83° east, distant three leagues. This island is moderately elevated, its shores pleasant and easy of access, and well stocked with timber, mostly of the pine tribe. It presented a much more inviting appearance than they had been accustomed to behold, and the weather being more favorable than for some time past, they continued along the continental shore,

passing within some islets that lie about a league to the eastward of the round island, until nine in the evening, when it became calm, and the party rested for the night at the entrance of a brook, in a bay on the northern or continental shore, which from the round island lies south 82° east, distant ten miles.*

If we understand this, the bay to the north is Glacier Bay, down which the ice must then have extended south of Willoughby Island and to within a few miles of Cross Sound. Otherwise no such description could have been given. The bay to the east is probably the extension of the sound toward the mouth of Lynn Canal, and very likely glaciers at that time came down toward the west from the White Mountains and produced the appearance described. From what has already been said of the evidence showing the present recession of the Muir Glacier, it is not at all incredible that glaciers nearly filled the whole bay a hundred years ago.

All this is necessary to a comprehension of a most interesting problem presented by the buried forests near the southwest corner of the glacier (see A, Fig. 24). Below this corner, and extending for about a mile and a half, there is a gravel deposit, similar to that on the eastern side, except that it is not marked by transverse ridges, but is level-topped, rising gradually from about 100 feet at its southern termination to a little over 300 feet where it extends north and west of the ice-front (see Fig. 24). The subglacial stream entering the inlet just below the southwest corner of the ice emerges from the ice about a mile farther up, on the north side of the projecting shoulder of the western mountain which forms that side of the gateway through which the glacier enters the inlet. This stream comes principally from the decaying western branch of the glacier before alluded to, and, after winding around the projecting shoulder of the mountain, which is 315 feet above tide, has worn a channel through the gravel

* "Voyage of Discovery around the World," vol. v, pp. 420–423.

deposit lying between the lower mile of the glacier and the mountain a short distance to the southwest. About half-way down, a small brook, coming from between this latter mountain and that whose shoulder forms the western part of the gateway just north of it, joins the main stream issuing from the glacier on this side. Where these streams unite, at A, they are now uncovering a forest of cedar-trees in perfect preservation, standing upright in the soil in which they

FIG. 27—Buried Forest on the Muir Glacier, looking west.

grew, with the *humus* still about their roots. An abundance of their cones, still preserving their shape, lies about their roots; and the texture of the wood is still unimpaired. One of these upright trunks measured ten feet in circumference about fifteen feet above the roots. Some of the smaller upright trees have their branches and twigs still intact, preserving the normal conical appearance of a recently dead cedar-tree.

These trees are in various stages of exposure. Some of

them are uncovered to the roots; some are washed wholly out of the soil; while others are still buried and standing upright, in horizontal layers of fine sand and gravel, some with tops projecting from a depth of twenty or thirty feet, others being doubtless entirely covered. The roots of these trees are in a compact, stiff clay stratum, blue in color, without grit, intersected by numerous minute rootlets, and which is, in places, twenty feet thick. There is also, occasionally, in this sub-

FIG. 28.—Shows stumps of trees on east side of the glacial torrent. Note the line of separation between the enveloping sand and the soil in which the roots are imbedded. A stump appears on the right, split in two, but one half standing. The gravel corresponds in height with that on the west side. The glacier appears in the background on the right. (From photograph, looking north.)

stratum of clay, a small fragment of wood, as well as some smooth pebbles from an inch to two feet in diameter. The surface of this substratum is at this point 85 feet above the inlet. The deposit of sand and gravel covering the forest rises 115 feet higher, and is level-topped at that height, but rising toward the north till it reaches the shoulder of the mountain at an elevation of 300 feet. The trees are essentially like those now growing on the Alaskan mountains. Many of them have been violently broken off from five to

twenty feet above their roots. This has been done by some force that has battered them from the upper side at the point of fracture. Evidently cakes of ice brought down by the streams indicated in the map, when flowing at various higher levels than now, have accomplished this result; for the trunks in the main stream were battered on the north side, while those in the gully worn by the lateral stream were battered from the west side.

From this description the explanation would seem to be evident. At some period, when the ice occupied only the upper part of the valley to the north of this point, forests grew over all the space lying southwest of the present ice-front. As the ice advanced to near its present position, the streams carrying off the surplus water from the western half of the advancing glacier were suddenly turned into the protected space occupied by this forest, where they deposited their loads of sand and gravel. A cause very likely combining to facilitate deposition in this spot has not yet been spoken of, but is evident from a glance at the maps. A transverse valley passes just below this point from Muir Inlet to the western inlet into which Glacier Bay divides. This transverse valley is at present occupied by a decaying glacier opening into both inlets, and sending a subglacial stream through a long, narrow series of moraines, into Muir Inlet about two miles to the south. Now, when a general advance of the ice was in progress, this transverse glacier probably pushed itself down into the inlet across the path of the ice moving from the north, and so formed an obstruction to the water running from the southwest corner of the main glacier, thus favoring the rapid deposition which so evidently took place. When this inclosed place was filled up, and the advancing ice had risen above and surmounted the projecting shoulder of the mountain just to the north, that rocky barrier protected a portion of the forest from the force of the ice-movement, causing the ice to move some distance over the top of the superincumbent gravel before exerting its full downward force. Thus sealed up on the lee side of this pro-

teeting ridge of rock, there would seem to be no limit to the length of time the forest might be preserved. I see no reason why this forest may not have existed before the Glacial period itself.

The existence of other forests similarly preserved in that vicinity is amply witnessed to by many facts. One upon the island near the west shore, four miles south, is now exposed in a similarly protected position. Furthermore, the moraine, already described on the east side of the inlet, contains much wood ground up into slivers and fragments. Indeed, our whole dependence during the month for fuel was upon such fragments lying exposed in the moraine. Occasional chunks of peat or compact masses of *sphagnum* formed a part of the *débris* of this moraine. These also occurred on some of the

FIG. 29—Muir Glacier from an elevation of 1,800 feet.

medial moraines on the eastern side. I did not go up them far enough to learn directly their origin; but, as no forests

were visible anywhere in that direction, it is presumable that they had been recently excavated from preglacial forests similar in situation to that now exposed on the west below the ice-front.

The capacity of the ice to move, without disturbing them, over such gravel deposits as covered the forests, is seen also in the present condition of the southwestern corner of the glacier itself. As the ice-front has retreated along that shore, large masses of ice are still to be seen lapping over upon the gravel. These are portions of the glacier still sustained in place by the underlying gravel, while the water of the inlet has carried the ice from the perpendicular bank clear away. This phenomenon, and that of the general perpendicular front presented by the ice at the water's edge, accord with the well-known fact that the surface of the ice moves faster than the lower portions. Otherwise the ice-columns at the front would not fall over into the water as they do.

The formation of kames, and of the knobs and kettle-holes characteristic both of kames and of terminal moraines, is illustrated in various places about the mouth of Muir Glacier, but especially near the southwest corner, just above the shoulder of the mountain where the last lateral branch comes in from the west. This branch is retreating, and has already begun to separate from the main glacier at its lower side, where the subglacial stream passing the buried forest emerges. Here a vast amount of water-worn *débris* covers the ice, extending up the glacier in the line of motion for a long distance. It is evident from the situation that, when the ice-stream was a little fuller than now, and the subglacial stream emerged considerably farther down, a great mass of *débris* was spread out on the ice at an elevation considerably above the bottom. Now that the front is retreating, this subglacial stream occupies a long tunnel, twenty-five or thirty feet high, in a stratum of ice that is overlaid to a depth, in some places, of fifteen or twenty feet with water-worn glacial *débris*. In numerous places the roof of this tunnel has broken in, and

the tunnel itself is now deserted for some distance by the stream, so that the *débris* is caving down into the bed of the old tunnel as the edges of ice melt away, thus forming a tortuous ridge, with projecting knolls where the funnels into the tunnel are oldest and largest. At the same time, the ice on the sides at some distance from the tunnel, where the superficial *débris* was thinner, has melted down much below the level of that which was protected by the thicker deposit; and so the *débris* is sliding down the sides as well as into the tunnel through the center. Thus three ridges approximately parallel are simultaneously forming—one in the middle of the tunnel and one on each side. When the ice has fully melted away, this *débris* will present all the complications of interlacing ridges, with numerous kettle-holes and knobs characterizing the kames; and these will be approximately parallel with the line of glacial motion. The same condition of things exists about the head of the subglacial stream on the east side, also near the junction of the first branch glacier on the east with the main stream, as also about the mouth of the independent glacier shown on the map lower down on the west side of the inlet (see Fig. 24). The formation of kettle-holes in the terminal ridges has already been referred to.

Considerable earthy material is carried out from the front by the bergs. Pebbles and dirt were frequently seen frozen into them as they were floating away. Just how many of the bergs were formed from ice that originally rested on the bottom of the inlet I have no means of telling. That some were so formed seems exceedingly probable, if for no other reasons because of the great amount of *débris* that was sometimes seen frozen into them. It is by no means certain that the subglacial streams boiling up near the upper corners of the inlet were beneath the lowest stratum of ice. Some small streams were seen pouring out from the face of the ice half way up from the water. It seems likely that a great amount of sediment is conveyed into cavities in the center of the glacier through the action of these subglacial streams; and so is ready for transportation when the masses break loose.

My estimates concerning the amount of sediment carried out by subglacial streams are as follows: The amount of sediment contained in each United States gallon (231 cubic inches) of water collected from the subglacial streams is, as determined by the analysis of the late Professor H. C. Foote, of Cleveland, 708·48 grains. Estimating the total area occupied by the glacial amphitheatre to be 1,200 square miles, and the annual precipitation the same as that at Sitka (which is not far from ninety-six inches), the total amount of water which must in some form annually pass into the inlet from this area is 267,632,640,000 cubic feet. Of this amount I estimate that 77,088,000,000 cubic feet passes out as ice, or, reducing this to water, about 67,000,000,000 cubic feet of liquid water. (This part of the calculation is based on the fact approximately ascertained that a section of ice one mile wide and 1,000 feet deep is moving into the inlet at a rate of 40 feet per day.) Subtracting the ice from the total amount, and estimating that evaporation would probably diminish the amount one eighth, the total amount of water which must issue in all the subglacial streams from this glacier is 175,000,000,000 cubic feet. Estimating the specific gravity of the sediment (which is chiefly some compound of alumina and silica) at two and a half, we have, as the total amount of sediment transported thus, 33,274,804 cubic yards. This equals not far from one third of an inch per year eroded from the total area (1,200 square miles) occupied by the glacier. This would furnish one inch of sediment per year to be spread by this single glacier over the bottom of Glacier Bay. This confirms the statements concerning the recent recession of the glacier from the lower portion of the bay, since otherwise it would now be full of sediment.

Besides the Muir Glacier several others of large size, such as the Grand Pacific and Hugh Miller Glaciers, descend from the flanks of Mts. Crillon and Fairweather into Reid Inlet, which projects several miles to the northwest from Glacier Bay. These do not differ materially in appearance and behavior from the Muir Glacier.

I append the record of the thermometer from August 20th to August 31st, giving the mean of three readings each day taken at 8 A. M., 2 P. M., and 8 P. M. The temperature of the water in the upper part of the inlet was uniformly 40° Fahr.

August 20, 49·4° Fahr.	August 24, 49·8° Fahr.	August 28, 50·5° Fahr.
August 21, 48·9° Fahr.	August 25, 52·7° Fahr.	August 29, 45° Fahr.
August 22, 46·1° Fahr.	August 26, 51·9° Fahr.	August 30, 54·8° Fahr.
August 23, 44·6° Fahr.	August 27, 46·1° Fahr.	August 31, 50·5° Fahr.

The following is the list of plants, as identified by Professor Asa Gray, found in bloom about Muir Inlet during the month of August. Where the altitude is not given, they were found near the tide:

Arabis ambigua, Brong.	August 26,	1,600 A. T.
Arenaria pepioides, L	August 28.	
Astragalus alpinus, L.	August 7.	
Hedysarum boreale, Nutt	August 28.	
Sanguisorba Canadensis.	August 6.	
Lutkea sibbaldioides, Brong.	August 27.	
Saxifraga Lyalli, Engl.	August 26.	1,600 A. T.
Saxifraga stellaris, L.	August 27,	3,000 A. T.
Parnassia fimbriata, Small	August 27,	3,000 A. T.
Parnassia palustris, L	August 6.	
Epilobium latifolium, L.	August 6,	1,600 A. T.
Epilobium origanifolium Lam. (?)	August 28.	
Solidago multiradiata, Ait.	August 27.	
Erigeron salsuginosus, Gray, arctic form	August 27,	3,000 A. T.
Antennaria margaritacea, arctic form	August 27.	
Achillea millefolium, L., arctic variety	August 27.	
Arnica obtusifolia, Les.	August 27,	1,200 A. T.
Campanula rotundifolia, L., var. Alaskana	August 28.	
Gentiana platypetala (?)	August 27.	
Gentiana Menziesii (?)	August 27.	
Mertensia maritima	August 7.	
Castilleja parviflora, Brong.	August 28.	
Salix vestita, Pursh	August 6.	
Habenaria hyperborea, R. Br.	August 27,	2,650 A. T.
Luzula parviflora, Meyer.		
Poa alpina, variety vivipara	August 26,	1,500 A. T.
Poa alpina, L.	August 26,	1,600 A. T.
Poa laxa, Haenke	August 26,	1,500 A. T.

Phleum alpinum, L.	August 26, 1,600 A. T.
Elymus mollis..........................	August 6.
Hordeum, sp. (?).......................	August 6.

FIG. 30.—Blocks of stone supported on ice-pillars, showing how they fall toward the sun. See above, page 49. United States Geological Survey (Russell).

SUPPLEMENT TO CHAPTER III.

For various reasons it is best to let this chapter stand as it was originally written. But it is necessary to append a summary of the results of subsequent observations by others, especially as they have a most important bearing on several questions of glacial theory. During the summers of 1890 and 1892 Professor Harry Fielding Reid with a corps of competent assistants carefully surveyed the region and made extensive additions to our knowledge, not only of this glacier, but of glacial movements in general.

The main facts, as determined by Professor Reid, do not, however, differ materially from ours. Our estimate of twelve hundred square miles for the area of the Muir Glacier would, by his calculations, be brought down to a thousand square miles. He failed, however, to detect any motion in the glacier greater than about ten feet per day. But it should be noted that he did not measure the central, and consequently most rapidly moving portion of the ice, but limited himself to calculating the motion of those portions of the ice which he could traverse, and upon which he could plant flags of observation. Thus, notwithstanding his utmost efforts, in going out from both directions, about a quarter of a mile in width, as he informs me, remained untraversed, and his attempts to take angles, after the method pursued by us, upon the masses of ice themselves, failed of success. This was probably due to the fact that his base-line (near B in our map on page 53) was eight hundred feet higher upon the mountain than ours, so that he did not have the advantage which we had of seeing the domes and pinnacles of the central and higher portion of the ice projected upon the sky and the dark background of the mountains beyond. Hence it does not appear that there is any occasion to question the approximate correctness of our figures as given on page 54. If, however, I were to revise the estimates of the average rate of movement in the mass of ice, I should not place it quite so high as I have done on page 55, especially since in that calculation no allowance was made for the decrease of velocity toward the bottom. Taking this into account, together with the com-

parative narrowness of the area of most rapid motion, the average movement of the mass is probably not over twenty feet per day, and this amount would perhaps account for the number of bergs floating away with the tide, especially since now we must add to them the amount supplied by the recession of the front of the ice.

With reference to the evidence of the recent recession of the glacier Professor Reid agrees entirely with me. By comparison of his photographs with mine he found that in "the four years from 1886 to 1890 the western end of the ice front has receded 1,200 yards and the eastern end 750 yards. The center also has receded about 1,000 yards, so that the average recession of the ice front is a little over 1,000 yards in the four years, or, say a mile in seven years . . . . It does not seem at all incredible that the ice from the various glaciers of Glacier Bay may have united to fill a large part of the bay 100 years ago."

But it is no longer necessary to depend on this evidence alone. In 1906 Messrs. F. E. and C. W. Wright made an official investigation of the region with the following startling results. On comparing their map with that of Professor Reid made in 1892 they write that:

Beginning with Muir Glacier and its tributaries the ice front has receded a maximum distance of 33,000 feet; Dirt Glacier is no longer tidal; White and Adams Glaciers are supplying very little ice to the general ice field; Morse Glacier terminus is about one mile from tide water . . . . Girdled Glacier and Berg Lake have not changed materially in aspect. The length of the total ice front of Muir Glacier is now over 40,000 feet instead of 9,000 feet in 1892. The present ice front passes at its northern extremity at about the position of your 1,000 foot contour on the ice of 1892. This remarkable decrease in elevation is undoubtedly due not only to melting down but also to breaking down of the exposed ice masses. The ascent of the ice mass at this point is decidedly steep and the ice fairly cascades into the water. The present height of the ice fronts of all the tide water glaciers is about the same

as noted by you in 1892 (150–250 feet), and is a noteworthy fact in connection with these glaciers. Muir Inlet is at present choked by the ice pack which promises to remain congested so long as its source of supply is so active. A considerable portion of the present front of Muir Glacier is in very shallow water and in a few years should decrease in size very materially unless new avenues and inlets for tidal currents are exposed by the receding ice. Dying Glacier is still creeping back and wasting away.

Carroll Glacier has not changed much in aspect during the last fourteen years; its terminal cliff has receded about 2,000 feet and at present, apparently, is continuing to do so. It is discharging icebergs very slowly and Queen Inlet is nearly free of ice.

Rendu Glacier has also changed but little, and its front is about 2,000 feet back of its position in 1892. This inlet also is not impeded by any amount of ice. The small glacier cascading from the west near its terminus appears to have changed still less.

In Reid Inlet the changes have been very great and things are still moving at a rapid rate there. The inlet was congested with the ice pack last summer (1906) and on the south side near the large island the ice jam was completely frozen over and moved as one mass back and forth with the tides.

Grand Pacific Glacier has receded and left the large granite island surrounded by water. It has receded nearly 20,000 feet; but judging from the amount of ice it is now discharging and the shape of its valley it will not recede so rapidly in the next few years, other conditions remaining the same.

Johns Hopkins Glacier has receded about 11,000 feet and is still sending off icebergs at a rapid rate. The unnamed glacier directly east has become detached from it and is much like Reid Glacier in character and appearance.

Reid Glacier has receded perhaps 5,000 feet and still preserves its original aspect as indicated on your map . . . .

Hugh Miller Glacier no longer reaches tide water in Reid Inlet and at low tide is nearly a mile back from it. The tide flats are long and with only a slight grade. In Hugh Miller

Inlet this glacier was exposed to tide water only in the southwestern bay, where its front is intercepted in its central part by a large promontory of light colored granite. Eight thousand feet is approximately its recession since 1892. Charpentier Glacier also receded about 9,000 feet and promises to continue its recession rapidly, especially along its southern front, as its valley is opening out and allowing a greater exposure of ice front to the action of tide water.

The small stagnant glacier east of Charpentier is simply melting away and will probably disappear in ten or twenty years.

Favorite Glacier is still receding. Wood Glacier is no longer tidal and only a small part of Geikie Glacier ice front is exposed to salt water. Geikie Glacier has receded about 5,000 feet during the past fourteen years.

On the whole, recession has been the rule for the glaciers of Glacier Bay. Those glaciers have receded most whose fronts have, on recession, increased appreciably in length. In the past fourteen years the combined ice front of all the glaciers exposed to the tide water has increased from 17,000 feet to over 40,000 feet and the amount of recession has in that time alone equalled that of the previous twenty years.

To the west of Glacier Bay, Brady Glacier in Taylor Bay has receded considerably. In Lituya Bay, the glacier at the northwestern end of the bay has advanced about one-half mile since 1894; the central and southeastern glaciers have apparently remained unchanged although the latter may have advanced slightly.*

* H. F. Reid: "Variation of Glaciers," xii, "Journal of Geology," xvi, pp. 52, 53.

CHAPTER IV.

THE GLACIERS OF GREENLAND.

The continental proportions of Greenland, and the extent to which its area is covered by glacial ice, make it by far the most important accessible field for glacial observations. The total area of Greenland can not be less than 500,000 square miles—equal in extent to the portion of the United States east of the Mississippi and north of the Ohio. It is now pretty evident that the whole of this area, except a narrow border about the southern end, is covered by one continuous sheet of moving ice, pressing outward on every side toward the open water of the surrounding seas.

For a long time it was the belief of many that a large region in the interior of Greenland was free from ice, and was perhaps inhabited. It was in part to solve this problem that Baron Nordenskiold set out upon his expedition of 1883. Ascending the ice-sheet from Disco Bay, in latitude 69°, he proceeded eastward for eighteen days across a continuous ice-field. Rivers were flowing in channels upon the surface like those cut on land in horizontal strata of shale or sandstone, only that the pure deep blue of the ice-walls were, by comparison, infinitely more beautiful. These rivers were not, however, perfectly continuous. After flowing for a distance in channels on the surface, they, one and all, plunged with deafening roar into some yawning crevasse, to find their way to the sea through subglacial channels. Numerous lakes with shores of ice were also encountered.

"On bending down the ear to the ice," says this explorer, "we could hear on every side a peculiar subterranean hum,

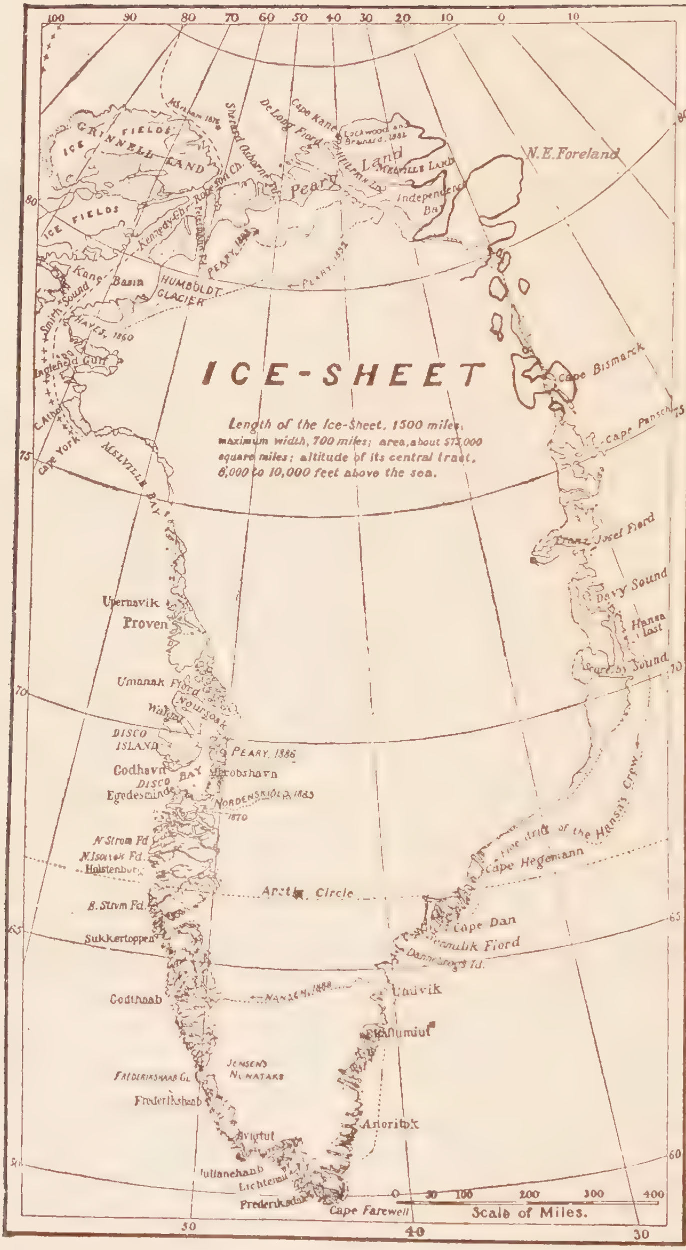

FIG. 31—Map of Greenland showing narrow margin free from ice.

proceeding from rivers flowing within the ice; and occasionally a loud single report like that of a cannon gave notice of the formation of a new glacier-cleft. . . . In the afternoon we saw at some distance from us a well-defined pillar of mist which, when we approached it, appeared to rise from a bottomless abyss, into which a mighty glacier river fell. The vast roaring water-mass had bored for itself a vertical hole, probably down to the rock, certainly more than 2,000 feet beneath, on which the glacier rested." *

At the end of the eighteen days, Nordenskiöld found himself about 150 miles from his starting-point, and about 5,000 feet above the sea. Here the party rested, and sent two Eskimos forward on *skidor*—a kind of long wooden skate, with which they could move rapidly over the ice, notwithstanding the numerous small circular holes which everywhere pitted the surface. These Eskimos were gone fifty-seven hours, having slept only four hours of the period. It is estimated that they made about 75 miles, and attained an altitude of 6,000 feet. The ice is reported as rising in distinct terraces, and as seemingly boundless beyond. If this is the case 225 miles from Disco Bay, there would seem little hope of finding in Greenland an interior freed from ice. So we may pretty confidently speak of that continental body of land as still enveloped in an ice-sheet. Up to about latitude 75°, however, the continent is fringed by a border of islands, over which there is no continuous covering of ice. In south Greenland the continuous ice-sheet is reached about thirty miles back from the shore.

In 1886 Dr. Rink wrote:

We are now able to demonstrate that a movement of ice from the central regions of Greenland to the coast continually goes on, and must be supposed to act upon the ground over which it is pushed, so as to detach and transport fragments of it for such a distance. . . . The plainest idea of the ice-formation here in question is given by comparing it with an inunda-

* "Geological Magazine," vol. ix, pp. 393, 399.

tion. . . . Only the marginal part shows irregularity; toward the interior the surface grows more and more level, and passes into a plain very slightly rising in the same direction. It has been proved that, ascending its extreme verge, where it has spread like a lava-stream over the lower ground in front of it, the irregularities are chiefly met with up to a height of 2,000 feet, but the distance from the margin in which the height is reached varies much. While under 68½° north latitude, it took twenty-four miles before this elevation was attained; in 62½° the same height was arrived at in half the distance. . . .

A general movement of the whole mass from the central regions toward the sea is still continued, but it concentrates its force to comparatively few points in the most extraordinary degree. These points are represented by the ice-fiords, through which the annual surplus ice is carried off in the shape of bergs. . . . In Danish Greenland are found five of the first, four of the second, and eight of the third (or least productive) class, besides a number of inlets which only receive insignificant fragments. Direct measurements of the velocity have now been applied on three first-rate and one second-rate fiords, all situated between 69° and 71° north latitude. The measurements have been repeated during the coldest and the warmest season, and connected with surveying and other investigations of the inlets and their environs. It is now proved that the glacier branches which produce the bergs proceed incessantly at a rate of thirty to fifty feet per diem; this movement being not at all influenced by the seasons. . . .

In the ice-fiord of Jakobshavn, which spreads its enormous bergs over Disco Bay, and probably far into the Atlantic, the productive part of the glacier is 4,500 metres (about 2½ miles) broad. The movement along its middle line, which is quicker than on the sides nearer the shores, can be rated at fifty feet per diem. The bulk of ice here annually forced into the sea would, if taken on the shore, make a mountain two miles long, two miles broad, and 1,000 feet high. The ice-fiord of Torsukatak receives four or five branches of the glacier; the most productive of them is about 9,000 metres (five miles) broad, and moves between sixteen and thirty-two feet per diem. The large Karajak Glacier, about 7,000 metres (four miles) broad,

proceeds at a rate of from twenty-two to thirty-eight feet per diem. Finally, a glacier branch dipping into the fiord of Jtivdliarsuk, 5,800 metres (three miles) broad, moved between twenty-four and forty-six feet per diem.*

Describing the "Isblink," in latitude 62½° north, Rink says:

The whole surveyed area of the inland ice in this place is calculated at 450 square miles, and forms, by means of the tongued shape of its foremost part, in some measure a separate district, in which the principal changes of the whole margin, excepting the ice-fiords, are represented. Toward the interior it is bordered by a row of *nunataks*,† distant about forty miles from the seaward edge which our travelers had ascended as their starting-point. Here the origin of the ice over which they had passed was at once plainly visible; namely, that it could not have been formed on the spot, but was brought thither from the interior of the continent. The nunataks had been an obstacle to this movement: on the east side, facing the interior, the ice was broken and piled up several hundred feet against the rock, like breakers of an ocean, while to the south and north, and between the nunataks, it poured down like frozen waterfalls to be embodied in and leveled with the crust over which our explorers had traveled. . . .

The recent explorations, as already mentioned, have proved that what now we designate as coast-land free from ice was formerly covered with ice like the interior. This ancient ice-covering reached, in the immediate vicinity of the present inland ice, a height of 3,000 to 4,000 feet, and, farther seaward, 2,000 to 3,000 feet above the sea. All the usual traces of ancient ice-action, the erratic blocks and the ground rocks, are the same here as in northern Europe.

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* See "Transactions of the Edinburgh Geological Society" for February 18, 1886, vol. v, part ii, pp. 286–293.

† *Nunataks* are simply mountain-tops projecting above the surface of the ice-fields, such as were described in the account of the Muir Glacier in Alaska. Nordenskiold was the first to describe them in Greenland, and gave them this name.

Rink supposes the opening of new channels for the outlet of the ice through the fiords may have so relieved the interior as to account for this recedence of the ice.*

Among the most important observations upon the rate of movement in the glaciers in Greenland are those made by the Norwegian geologist Helland, in the summer of 1875. During that season he made a series of measurements on the glacier that enters the great Jakobshavn Fiord in the northern part of Disco Bay, about latitude 70°. The width of this glacier near its mouth he found to be about two miles and a half. The view from the peaks in the vicinity toward the east extended to a continuous ice-field on the distant horizon. The rate of motion reported by Helland was so great, that scientific men hesitated for some time to credit it. According to his measurements, the Jakobshavn Glacier, in the central portion of its current, was moving more than sixty feet per day, as compared with the three feet per day reported for Alpine glaciers. But the subsequent measurements of Steenstrup, given above, and those of my own upon the Muir Glacier in Alaska (made in 1886), amply sustain the conclusions of Helland.

It is proper to observe here, again, that the movement of glacial ice is affected much less by the slope of its bottom than by the size of the stream itself. The friction of the ice upon the bottom and sides of its channel is so great, that, where the stream is both shallow and narrow, the motion must be almost completely retarded. On doubling the size

* The list of explorers given by Rink is worthy of being honored, and is as follows: "Geologist K. J. V. Steenstrup (eight summers and two winters); Lieutenant G. Holm, of the Royal Navy (five summers and one winter); Lieutenant R. Hammer, of the Royal Navy (three summers and one winter); Lieutenant A. D. Jensen, of the Royal Navy (three summers); geologist Sylow (two summers); painter Groth (two summers); supernumerary officer Larsen (one summer); Lieutenant Garde, of the Royal Navy (two summers and one winter); geologist Knutsen, Norwegian (two summers and one winter); geologist Petersen (one summer); botanist Eberlin (two summers and one winter); painter Rüs Carstersen (one summer). Steenstrup and Hammer did most on the fiords."

of a semi-fluid stream, the relative amount of friction becomes very much less, so that it will move more than twice

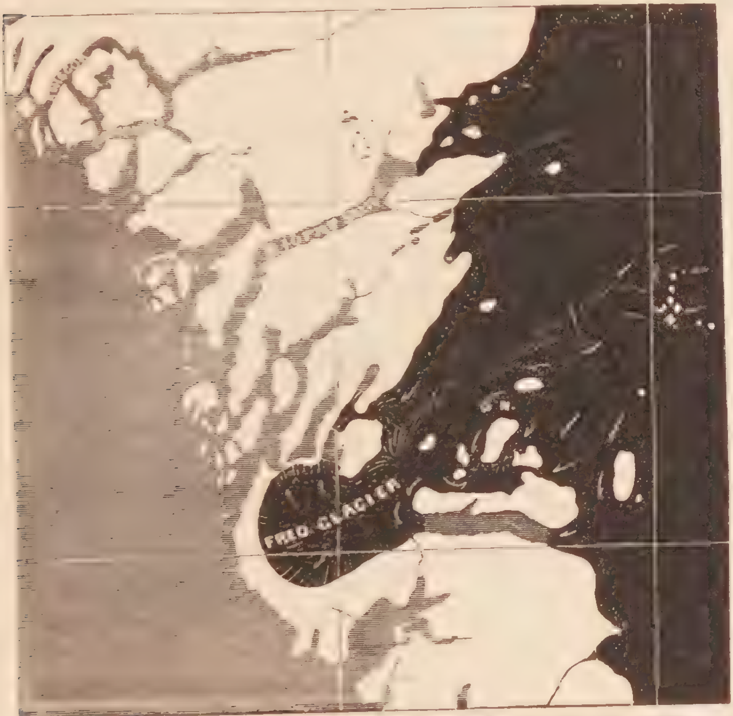

Fig. [illegible].—Map of Frederikshaab Glacier between 62° and 63°, showing course of Lieutenant Jensen's [illegible] The black part [illegible]; white, [illegible] shaded water; J. N., Jensen's nunataks; D. N., Dalager's nunataks; white lines on the black, crevasses; arrows, glacier flow. Five species of plants were found on the nunataks which still survive on the White Mountains (N. H.). Dana.

as fast as before. This property of a semi-fluid is made sufficiently evident from a homely illustration. Molasses in cold weather will scarcely run at all through a gimlet-hole, while it will run with considerable freedom through an auger-hole. Now, the glaciers of the Alps, which were the subjects of Professor Tyndall's measurements, were, in comparison to those in Greenland and Alaska, about in the proportion of a small gimlet-hole to a large auger-hole, and the faster motion is really not surprising.

Helland's observations as to the amount of ice floating away from the glacier in bergs amply confirm the direct calculation. The depth of the Jakobshavn Fiord is about 1,200 feet, so that icebergs of vast size can float off upon its waters. The daily discharge of ice through this fiord was estimated by him to be 432,000,000 cubic feet—about three times the calculation I have made for the Muir Glacier in Alaska. In addition to the formation of large icebergs, the discharge of ice from such a glacier as that at Jakobshavn is doubtless accompanied by a continual cannonade of countless smaller fragments, keeping the heavens full of thundering sounds and the waters full of commotion. From this it follows that the movement of the great glaciers *must* be rapid, to account for the enormous numbers of first-class icebergs which are encountered in the vicinity, and for the numerous and immense ice-floes composed of smaller fragments.

While the attention is fixed on the movement of the glaciers, we should not fail to note the uniform presence of subglacial streams of water emerging from their fronts. Such streams are usually in proportion to the size of the glacier, and, as already remarked, are most powerful agencies in the transportation of earthy material. The amount of sediment thus brought out by a single subglacial stream on the west coast of Greenland is estimated to be from 15,000 to 20,000 tons daily; and the amount of water discharged in the stream is far larger than that which passes off as ice.

The existence of such subglacial streams reveals much concerning the condition of the glaciers themselves. The question at once arises, Whence does the water come? The answer is found in the facts already mentioned by Nordenskiöld concerning the superficial streams of water uniformly encountered on penetrating the glaciated interior of Greenland. Doubtless, also, much water arises from the melting of the lower strata of ice through the heat produced by the friction attendant upon the motion.

Mr. Whymper's descriptions add vividness to our knowledge of the Greenland Glacier in the latitude of Disco:

In a paper communicated to the "Alpine Journal" in 1870, I wrote in relation to this part of Greenland and the country to its north and south:

The great ice-covered interior plateau of Greenland can be seen a long way off if the weather is clear. Its summit is

Fig. 33.—Ikamiut Fjord, Greenland, showing hanging glaciers. Glaciers at head of the Fjord come to water's edge.

almost a dead level from north to south. But when one comes nearer to the coast it is concealed by the hills which are on its out-skirts. The whole of the (outer) land on the (west) Greenland coast is mountainous, and although the hills scarcely ever, if ever, exceed a height of 8000 or 9000 feet, they effectually conceal the inner or glacier-covered land. This latter is at a distance from the coast varying from ten to sixty or more miles, and, when it is reached, there is an end to land—all is ice, as far as the eye can see. Great as the mass of ice is which still envelops Greenland, there were times when the land was even more completely covered up by it; indeed, there is good reason to suppose that there was a time when every atom of the country was covered, and that life was hardly possible for man. . . . With the exception of places where the rocks are easy of disintegra-

tion, and the traces of glacier action have been to a great extent destroyed, the whole country bears the marks of the grinding and polishing of ice; and, judging by the flatness of the curves of the *roches moutonnées*, and by the perfection of the polish which still remains upon the rocks, after they have sustained many centuries of extreme variations of temperature, the Glacial period during which such effects were produced must have vastly exceeded in duration, or severity, the Glacial period of Europe; and the existing great interior ice-plateau of Greenland, enormous as it is, must be considered as but the remnant of a mass which was incalculably greater, and to which there is no parallel at the present time, excepting within the Antarctic Circle.

And later on, in my book, "Scrambles among the Alps," 1871, pages 246, 247:

The interior of Greenland appears to be absolutely covered by a glacier between 68° 30′–70° north latitude. . . . On two occasions, in 1867, I saw, at a glance, at least 6,000 square miles of it from the summits of small mountains on its outskirts. Not a single peak or ridge was to be seen rising above, nor a single rock reposing upon the ice. The country was *completely* covered up by glaciers; all was ice, as far as the eye could see. . . . This vast ice-plateau, although smaller than it was in former times, is still so extensive that the whole of the glaciers of the Alps might be merged into it without its bulk being perceptibly increased.

In 1872 I again traveled in northwestern Greenland, and by ascending various lofty mountains saw more of the "inland ice"; and in the "Alpine Journal" for 1873, page 220, I wrote:

From all the principal summits you perceive the vast glacier-clad interior of the country, stretching from north to south in an unbroken line, with a crest as straight as a sea-horizon. There are no marks upon it which enable one to calculate the altitude to which it rises, or the distance to which it extends. But having now seen it from several elevated and widely separated positions, as I find that its summit-line always appears lofty, even from the highest mountains which I have ascended, my impression is that its height is generally not less

than 8,000 feet, and in some places, perhaps, surpasses 10,000 feet. . . .

On ascending hills on the outskirts I again had extensive views to the east, finding the land, as before, absolutely covered by glaciers. From the nearest parts to the farthest distance that could be seen, the whole of the ice was broken up into *séracs*. It was almost everywhere riven and fissured in a most extreme manner, and it was obviously totally impracticable for sledges. . . .

From the repeated views of the interior which had been seen from the coast mountains, it was clear that all this part of Greenland, except the fringe of land on the Davis Strait side, was absolutely covered by snow and ice, and that the interior was not broken up in those latitudes as I had conjectured it might be. . . .

This vast glacier is the largest continuous mass of ice at present known. All the glaciers of the Alps combined are as nothing to it, and the greatest of those in the Himalayas are mere dwarfs in comparison. At Jakobshavn the bergs floating away were often from 700 to 800 feet thick, and this is the only information at present possessed of its *depth*. The angle at which its surface rises toward the east is very slight, being seldom so much as 8°, and generally much less; while in some places there are considerable depressions, and lakes are formed in consequence. . . .

Mount Kelertingouit was 6,800 feet high, and there was a grand and most interesting view from its summit in all directions. Southward it commanded the whole breadth of the Noursoak Peninsula, and extended over the Waigat Strait to the lofty island of Disco; westward it embraced the western part of the Noursoak Peninsula, with Davis Strait beyond; northward it passed right over the Umenak Fiord (some thirty miles wide) to the Black Hook Peninsula; to the northeast it was occupied by the fiord, with its many imposing islands and islets, surrounded by innumerable icebergs streaming away from the inland ice; and in the east, extending from northeast to southeast, over well-nigh 90° of the horizon, there was the inland ice itself—presenting the characteristic features which have been mentioned in the earlier papers. The south-

ern part of the view of the inland ice, as seen from Kelertingouit, overlapped the northern part of it as seen on former occasions, while northward it extended to at least 71° 15′ north latitude, so I had now viewed the section of the interior between 68° 30′ and 71° 15′, equal to 190 English miles, and had everywhere found a straight, unbroken crest of snow-covered ice, concealing the land so absolutely that not a single crag appeared above its surface.

The height of this straight, unbroken crest of snow was now the object of attention—the principal object for which the ascent was made. On bringing the theodolite to bear upon it, I found that it *appeared* to be slightly depressed below my station; but, as it was distant more than one hundred miles, it was only lower *in appearance* and not in reality. On the assumption that it was no more than one hundred miles distant, after making allowance for the refraction and curvature of the earth, its height was found to be *considerably in excess of ten thousand feet.**

Northward from this point explorations have been carried on incessantly since the middle of the last century beginning with the expeditions of Drs. Kane and Hayes between the years 1855 and 1862. These remarkable men were associated from 1853 to 1855, in the second Grinnell Expedition in search of Sir John Franklin, which succeeded in exploring the coast on the east side of Smith Sound from Cape Alexander, in latitude 78°, to Washington Land, in latitude 80°; while in 1861 and 1862 Dr. Hayes conducted an independent expedition to Lady Franklin Bay, in latitude 82°, and resurveyed portions of his former field.

In the neighborhood of Cape Dudley Digges, about latitude 76°, Dr. Kane's party encountered a glacier which he describes as follows:

This glacier was about seven miles across at its "debouche"; it sloped gradually upward for some five miles back,

* "Explorations in Greenland," "Choice Literature," 1884, pp. 170, 253, 308.

and then, following the irregularities of its rocky substructure, suddenly became a steep crevassed hill, ascending in abrupt terraces. Then came two intervals of less rugged ice, from which the glacier passed into the great *mer de glace.*

On ascending a high, craggy hill to the northward, I had a sublime prospect of this great frozen ocean, which seems to form the continental axis of Greenland—a vast, undulating plain of purple-tinted ice, studded with islands, and absolutely gemming the horizon with the varied glitter of sun-tipped crystal.

The discharge of water from the lower surface of the glacier exceeded that of any of the northern glaciers except that of Humboldt and the one near Etah. One torrent on the side nearest me overran the ice-foot from two to five feet in depth, and spread itself upon the floes for several hundred yards; and another, finding its outlet near the summit of the glacier, broke over the rocks and poured in cataracts upon the beach below.*

Between Wolstenholme Sound and Murchison Strait, about latitude 76° 60′, Tyndall Glacier comes down to the sea in a broad current ten or twelve miles in width; while twenty or twenty-five miles to the north, on Northumberland Island, a curious glacier is described by Kane, which he calls a "hanging glacier," and named after his brother John. "It seemed," he says, "as if a caldron of ice inside the coast-ridge was boiling over, and throwing its crust in huge fragments from the overhanging lip into the sea below. The glacier must have been eleven hundred feet high; but even at its summit we could see the lines of viscous movement." †

Upon another point in this island a glacier was encountered which affords Dr. Kane opportunity to remark upon some points not often noticed. The party had encamped on a low beach at the foot of a moraine which came down between precipitous cliffs of surpassing wildness. While there, he says:

* "Arctic Explorations in the Years 1853, 1854, 1855," vol. ii, pp. 270–272.

† Ibid., pp. 259, 260.

I was greatly interested by a glacier that occupied the head of the moraine. It came down abruptly from the central plateau of the island, with an angle of descent of more than seventy degrees. I have never seen one that illustrated more beautifully the viscous or semi-solid movement of these masses. Like a well-known glacier of the Alps, it had two planes of descent: the upper nearly precipitous for about four hundred feet from the summit; the lower of about the same height, but with an angle of some fifty degrees; the two communicating by a slightly inclined platform perhaps half a mile long. This ice was unbroken through its entire extent. It came down from the level of the upper country, a vast icicle, with the folds or waves impressed upon it by its onward motion undisturbed by any apparent fracture or crevasse. Thus it rolled onward over the rugged and contracting platform below, and thence poured its semi-solid mass down upon the plain. Where it encountered occasional knobs of rock it passed round them, bearing still the distinctive marks of an imperfect fluid obstructed in its descent; and its lower fall described a dome, or, to use the more accurate simile of Forbes, a great outspread clam-shell of ice.

It seemed as if an interior ice-lake was rising above the brink of the cliffs that confined it. In many places it could be seen exuding or forcing its way over the very crest of the rocks, and hanging down in huge icy stalactites seventy and one hundred feet long. These were still lengthening out by the continuous overflow, some of them breaking off as their weight became too great for their tenacity, others swelling by constant supplies from the interior, but spitting off fragmentary masses with an unremitting clamor. The plain below these cataractine glaciers was piling up with the *débris*, while torrents of the melted rubbish found their way, foaming and muddy, to the sea, carrying gravel and rocks along with them.

These ice-cascades, as we called them, kept up their din the whole night, sometimes startling us with a heavy booming sound, as the larger masses fell, but more generally rattling away like the random fires of a militia parade. On examining the ice of which they were made up, I found grains of *névé* larger than a walnut; so large, indeed, that it was hard to re-

alize that they could be formed by the ordinary granulating processes of the winter snows. My impression is, that the surface of the plateau-ice, the *mer de glace* of the island, is made up of these agglomerated nodules, and that they are forced out and discarded by the advance of the more compact ice from higher levels.*

The winter of 1853 and 1854 was spent by Dr. Kane in Van Rensselaer Harbor, in latitude 78° 60′. From this point Dr. Hayes and a small party were sent inland for the purpose of securing, if possible, some game to eke out their ship-supplies of food. They reported that, "after penetrating the interior about ninety miles, their progress was arrested by a glacier four hundred feet high, and extending to the north and west as far as the eye could reach." On his second expedition, in 1860, Dr. Hayes penetrated this same region again, starting from Port Foulke, about twenty miles to the southwest venturing, this time, some distance out on the surface of the glacier. The following is his own vivid description of the ice-field, beginning with the narrative of his first expedition.

At length we emerged upon a broad plain or valley, wider than any we had yet seen, in the heart of which reposed a lake about two miles in length by half a mile in width, over the transparent, glassy surface of which we walked. On either side of us rose rugged bluffs, that stretched off into long lines of hills, culminating in series in a broad-topped mountain-ridge, which, running away to right and left, was cut by a gap several miles wide that opened directly before us. Immediately in front was a low hill, around the base of which flowed upon either side the branches of the stream which we had followed. Leaving the bed of the river just above the lake, we ascended to the top of this hillock; and here a sight burst upon us, grand and imposing beyond any power of mine adequately to describe. From the rocky bed, only a few miles in advance, a sloping wall of pure whiteness rose to a broad level plain of ice

* "Arctic Explorations," vol. i, pp. 334–336.

which, apparently boundless, stretched away toward the unknown east. It was the great *mer de glace* of the Arctic Continent.

At any subsequent period of the cruise this sight would have less impressed me; but I had never, except in the distance, seen a glacier. Here before us was, in reality, the counterpart of the river-system of other lands. From behind the granite hills the congealed drainings of the interior water-sheds, the atmospheric precipitations of ages, were moving as a solid though plastic mass, down through every gap in the mountains, swallowing up the rocks, filling the valleys, submerging the hills—an onward, irresistible, crystal tide, swelling to the ocean. Cutting the surface were many vertical crevasses, or gutters, some of great depth, which had drained off the melted snow.

It was midnight when we made our approach. The sun was several degrees beneath the horizon, and afforded us a faint twilight. Stars of the second magnitude were dimly visible in the northern heavens. When we were within about half a mile of the icy wall, a brilliant meteor fell before us, and, by its reflection upon the glassy surface beneath, greatly heightened the effect of the scene; while loud reports, like distant thunder or the booming of artillery, broke at intervals from the heart of the frozen sea.

Upon close inspection we found the face of the glacier to ascend at an angle of from thirty to thirty-five degrees. At its base lay a high snow-bank, up which we clambered about sixty feet; but beyond this the ice was so smooth as to defy our efforts. The mountains, which stood like giant gate-posts on either side, were overlapped and partially submerged by the glacier. From the face of this a multitude of little rivulets ran down the gutters already mentioned, or gurgled from beneath the ice, and formed, on the level lands below, a sort of marsh, not twenty yards from the icy wall. Here grew, in strange contrast, beds of green moss; and in these, tufts of dwarf willows were twining their tiny arms and rootlets about the feebler flower-growths; and there, clustered together, crouched among the grass, and sheltered by the leaves, and feeding on the bed of lichens, I found a white-blossomed draba

which would have needed only a lady's thimble for a flower-pot, and a white chickweed. Dotting the few feet of green around me were seen the yellow blossoms of the more hardy poppy, the purple potentilla, and the white, purple, and yellow saxifrages.

This little oasis was literally imbedded in ice. The water which had flowed through it had frozen in the holes, and spread itself out in a crystal sheet upon the rocks and stones around. A few specimens of the tiny blossoms were laid in my note-book, a sprig of heather and a saxifrage were stuck in my button-hole, and with these souvenirs we left this garden-spot which the glacier was soon to cover forever from human eyes. . . .

In the autumn of 1860 I was favored with an opportunity to make a more important exploration of this great *mer de glace*, having from my winter harbor at Port Foulke ascertained that it had broken through the mountain-chain at the head of the bay in which my harbor was situated, and was there approaching the sea. Up this glacier, which had thus forced the rocky ramparts, I made my way with a small party of men, attaining an altitude of about 5,000 feet, and extending my observations seventy miles from the coast. The journey possessed the more value that it was entirely novel as regards the interior of Greenland. I was finally driven back by a severe gale of wind, which, being accompanied by a sudden fall of temperature, placed my party, for the time, in great jeopardy, as my tent afforded no shelter; but I had gone far enough to determine, with some degree of accuracy, the character of the interior; and the information thus acquired, in connection with my journey with Mr. Wilson in 1853, as just related furnishes an important addition to our knowledge of the great glacier system of the Greenland Continent. Eastward from the position attained on both of these journeys no mountains were visible—nothing but a uniform inclined plane of whiteness, a solid sea of ice, hundreds and hundreds of feet in depth, steadily rising until lost in the distance against the sky. A full description of the journey of 1860 has been published in my "Open Polar Sea."

This vast body of ice, now known as Humboldt Glacier, is

the largest glacier known, being about sixty miles across, and through at least one half of that extent discharging icebergs. Like the glacier already spoken of as having broken through the mountains near Port Foulke, this Humboldt Glacier has overcome the mountain-barriers, and poured down into the sea between Greenland and Washington Land, which latter is probably an island, lying in the expansion of Smith Sound (or Strait, as named by Dr. Kane), the water flowing to the eastward of Washington Land being now entirely replaced by the glacier. From Humboldt Glacier the face of the *mer de glace* sweeps around behind the mountain-chain in a curve toward Port Foulke. At the point reached by Mr. Wilson and myself, the ice was breaking through the mountains, nearly midway between these two extremes of the curve, and will, at some remote period, find its way into Smith Sound through the tortuous valley which now forms the bed of Mary Minturn River. South of Port Foulke the face of the *mer de glace* forms a series of similar curves of greater or less extent, and through all the great valleys of the Greenland coast-range, glaciers discharge into Baffin Bay their streams of icebergs. Several of these glaciers are from five to twenty miles across, and those of Melville Bay are doubtless much more extensive.*

This great Humboldt Glacier enters Peabody Bay from the east, filling the whole space from latitude 79° to 80°. There is, however, a vast movement of glacier-ice toward this point from the southeast. The face of the Humboldt Glacier is described by Dr. Kane as everywhere, for a distance of more than sixty miles, an "abrupt and threatening precipice, only broken by clefts and deep ravines, giving breadth and interest to its wild expression." † The party which first saw this majestic ice-front were compelled to traverse its entire breadth on the ice which had formed outside it in the months of September and October. A chief peril of their situation arose from the discharging

* "An Arctic Boat-Journey," pp. 10–12, 377, 378.

† "Arctic Explorations," vol. i, p. 222.

bergs of the great glacier which broke up the ice for miles around, at one time producing, directly under their tent, a fissure in the ice on which they had camped for the night. Repeatedly they were compelled to ferry themselves over the cracks in the ice on the bay by rafts of ice.*

Kane gives his first impressions of this grand glacier in the following vivid description:

I will not attempt to do better by florid description. Men only rhapsodize about Niagara and the ocean. My notes speak simply of the "long, ever-shining line of cliff diminished to a well-pointed wedge in the perspective"; and, again, of "the face of glistening ice, sweeping in a long curve from the low interior, the facets in front intensely illuminated by the sun." But this line of cliff rose in a solid, glassy wall 300 feet above the water-level, with an unknown, unfathomable depth below it; and its curved face, sixty miles in length from Cape Agassiz to Cape Forbes, vanished into unknown space at not more than a single day's railroad-travel from the pole. The interior, with which it communicated and from which it issued, was an unsurveyed *mer de glace*—an ice-ocean, to the eye, of boundless dimensions.

It was in full sight—the mighty crystal bridge which connects the two continents of America and Greenland. I say continents; for Greenland, however insulated it may ultimately prove to be, is in mass strictly continental. Its least possible axis, measured from Cape Farewell to the line of this glacier, in the neighborhood of the eightieth parallel, gives a length of more than 1,200 miles, not materially less than that of Australia from its northern to its southern cape.

Imagine, now, the center of such a continent, occupied through nearly its whole extent by a deep, unbroken sea of ice that gathers perennial increase from the water-shed of vast snow-covered mountains and all the precipitations of its atmosphere upon its own surface. Imagine this, moving onward like a great glacial river, seeking outlets at every fiord and valley, rolling icy cataracts into the Atlantic and Greenland

* "Arctic Explorations," vol. i, p. 135.

seas; and, having at last reached the northern limit of the land that has borne it up, pouring out a mighty frozen torrent into unknown arctic space.

It is thus, and only thus, that we must form a just conception of a phenomenon like this great glacier. I had looked in my own mind for such an appearance, should I ever be fortunate enough to reach the northern coast of Greenland. But, now that it was before me, I could hardly realize it. I had recognized, in my quiet library at home, the beautiful analogies which Forbes and Studer have developed between the glacier and the river. But I could not comprehend, at first, this complete substitution of ice for water.

It was slowly that the conviction dawned on me that I was looking upon the counterpart of the great river-system of Arctic Asia and America. Yet here were no water-feeders from the south. Every particle of moisture had its origin within the polar circle, and had been converted into ice. There were no vast alluvions, no forest or animal traces borne down by liquid torrents. Here was a plastic, moving, semi-solid mass, obliterating life, swallowing rocks and islands, and plowing its way with irresistible march through the crust of an investing sea.*

The following summer Dr. Kane visited the scene again, and gives many additional particulars:

I had not [he writes] realized fully the spectacle of this stupendous monument of frost. I had seen it for some hours hanging over the ice like a white-mist cloud, but now it rose up before me clearly defined and almost precipitous. The whole horizon, so vague and shadowy before, was broken by long lines of icebergs; and as the dogs, cheered by the cries of their wild drivers, went on, losing themselves deeper and deeper in the labyrinth, it seemed like closing around us the walls of an icy world. They stopped at last; and I had time, while my companions rested and fed, to climb one of the highest bergs. The atmosphere favored me: the blue tops of Washington Land [to the north] were in full view, and,

* "Arctic Explorations," vol. i, pp. 225–228.

losing itself in a dark water-cloud, the noble head-land of John Barrow.

The trend of this glacier is a few degrees to the west of north. We followed its face afterward, edging in for the Greenland coast, about the rocky archipelago which I have named after the Advance. From one of these rugged islets, the nearest to the glacier which could be approached with anything like safety, I could see another island, larger and closer in shore, already half covered by the encroaching face of the glacier, and great masses of ice still detaching themselves and splintering as they fell upon that portion which protruded. Repose was not the characteristic of this seemingly solid mass; every feature indicated activity, energy, movement.

The surface seemed to follow that of the basis-country over which it flowed. It was undulating about the horizon, but as it descended toward the sea it represented a broken plain with a general inclination of some nine degrees, still diminishing toward the foreground. Crevasses, in the distance mere wrinkles, expanded as they came nearer, and were crossed almost at right angles by long, continuous lines of fracture parallel with the face of the glacier.

These lines, too, scarcely traceable in the far distance, widened as they approached the sea until they formed a gigantic stairway. It seemed as though the ice had lost its support below, and that the mass was let down from above in a series of steps. Such an action, owing to the heat derived from the soil, the excessive surface-drainage, and the constant abrasion of the sea, must in reality take place. My note-book may enable me at some future day to develop its details. I have referred to this as the escaladed structure of the arctic glacier.

The indication of a great propelling agency seemed to be just commencing at the time I was observing it. These split-off lines of ice were evidently in motion, pressed on by those behind, but still widening their fissures, as if the impelling action was more and more energetic nearer the water, till at last they floated away in the form of icebergs. Long files of these detached masses could be traced slowly sailing off into the distance, their separation marked by dark parallel shadow-

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—broad and spacious avenues near the eye, but narrowed in the perspective to mere lines. A more impressive illustration of the forces of Nature can hardly be conceived. . . .

The frozen masses before me were similar in structure to the Alpine and Norwegian ice-growths. It would be foreign to the character of this book to enter upon the discussion which the remark suggests; but it will be seen by the sketch, imperfect as it is, that their face presented nearly all the characteristic features of the Swiss Alps. The "overflow," as I have called the viscous overlapping of the surface, was more clearly marked than upon any Alpine glacier with which I am acquainted. When close to the island-rocks, and looking out upon the upper table of the glacier, I was struck with the homely analogy of the batter-cake spreading itself out under the ladle of the housewife, the upper surface less affected by friction, and rolling forward in consequence.

The crevasses bore the marks of direct fracture and the more gradual action of surface-drainage. The extensive watershed between their converging planes gave to the icy surface most of the hydrographic features of a river-system. The ice-born rivers which divided them were margined occasionally with spires of discolored ice, and generally lost themselves in the central areas of the glacier before reaching its foreground. Occasionally, too, the face of the glacier was cut by vertical lines, which, as in the Alpine growths, were evidently outlets for the surface-drainage. Everything was, of course, bound in solid ice when I looked at it; but the evidences of torrent-action were unequivocal, and Mr. Bonsall and Mr. Morton, at their visits of the preceding year, found both cascades and water-tunnels in abundance.

The height of this ice-wall at the nearest point was about three hundred feet, measured from the water's edge; and the unbroken right line of its diminishing perspective showed that this might be regarded as its constant measurement. It seemed, in fact, a great icy table-land, abutting with a clean precipice against the sea. This is, indeed, characteristic of all those arctic glaciers which issue from central reservoirs, or *mers de glace*, upon the fiords or bays, and is strikingly in contrast with the dependent or hanging glacier of the ravines,

where every line and furrow and chasm seems to indicate the movement of descent and the mechanical disturbances which have retarded it.

I have named this great glacier after Alexander von Humboldt, and the cape which flanks it on the Greenland coast after Professor Agassiz.

The point at which this immense body of ice enters the land of Washington gives even to a distant view impressive indications of its plastic or semi-solid character. No one could resist the impression of fluidity conveyed by its peculiar markings. I have named it Cape Forbes, after the eminent crystalologist whose views it so abundantly confirms.

As the surface of the glacier receded to the south, its face seemed broken with piles of earth and rock-stained rubbish, till far back in the interior it was hidden from me by the slope of a hill. Still beyond this, however, the white blink or glare of the sky above showed its continued extension.

It was more difficult to trace this outline to the northward, on account of the immense discharges at its base. The talus of its descent from the interior, looking far off to the east, ranged from seven to fifteen degrees, so broken by the crevasses, however, as to give the effect of an inclined plane only in the distance. A few black knobs rose from the white snow, like islands from the sea.

The general configuration of its surface showed how it adapted itself to the inequalities of the basis-country beneath. There was every modification of hill and valley, just as upon land. Thus diversified in its aspect, it stretches to the north till it bounds upon the new land of Washington, cementing into one the Greenland of the Scandinavian Vikings and the America of Columbus.*

Much less is known concerning the eastern coast of Greenland than about the western coast. For a long time it was supposed that there might be a considerable population in the lower latitudes along the eastern side. But that is now proved to be a mistake. The whole coast is very inhos-

* "Arctic Explorations," vol. ii, pp. 146–153

pitable and difficult of approach. From latitude 65° to latitude 69° little or nothing is known of it. In 1822–'23 Scoresby, Cleavering, and Sabine, hastily explored the coast from latitude 69° to 76°, and reported numerous glaciers descending to the sea-level through extensive fiords, from which immense icebergs float out and render navigation dangerous. In 1869 and 1870 the second North German Expedition partially explored the coast between latitude 73° and 77°. Mr. Payer, an experienced Alpine explorer, who accompanied the expedition, reports the country as much broken, and the glaciers as "subordinated in position to the higher peaks, and having their moraines, both lateral and terminal, like those of the Alpine ranges, and on a still grander scale." Petermann Peak, in latitude 73°, is reported as 13,000 feet high. Captain Koldewey, chief of the expedition, found extensive plateaus on the mainland, in latitude 75°, to be "entirely clear of snow, although only sparsely covered with vegetation." The mountains in this vicinity, also, rising to a height of more than 2,000 feet, were free from snow in the summer. Some of the fiords in this vicinity penetrate the continent through several degrees of longitude. An interesting episode of this expedition was the experience of the crew of the ship Hansa, which was caught in the ice and destroyed. The crew, however, escaped by encamping on the ice-floe which had crushed their ship. From this, as it slowly floated toward the south through several degrees of latitude, they had opportunity to make many important observations upon the continent itself. As viewed from this unique position, the coast had the appearance everywhere of being precipitous, with mountains of considerable height rising in the background, from which numerous small glaciers descended to the sea-level.

In 1888 Dr. F. Nansen, with Lieutenant Sverdrup and four others, was left by a whaler on the ice-pack bordering the east of Greenland about latitude 65°, and in sight of the coast. For twelve days the party was on the ice-pack floating south, and so actually reached the coast only about lati-

tude 64°. From this point they attempted to cross the inland ice in a northwesterly direction toward Christianshaab. They soon reached a height of 7,000 feet, and were compelled by severe northerly storms to diverge from their course, taking a direction more to the west. The greatest height attained was 9,500 feet, and the party arrived on the western coast at Ameralik Fiord, a little south of Gotthaab, about the same latitude at which they entered.

In 1892, and again in 1895, Lieutenant Robert E. Peary set out from Inglefield Gulf (latitude 77° 40′), and traveling in a northeasterly direction for a distance of something over five hundred miles, crossed the Greenland ice-sheet, and came out near latitude 82° and longitude 40°. He succeeded in mapping a considerable portion of the northern coast, and in demonstrating that Greenland is really an island, with smaller islands to the north. Glaciers were found here flowing to the north, while there was much vegetation supporting herds of musk-ox and other forms of life. The interior ice was found to be of a pretty uniform height, ranging from 5,000 to 9,000 feet above tide. Indeed, the conditions did not materially differ from those found by Nansen fifteen degrees farther south.

In 1907 M. Erichsen, in charge of a Danish expedition, pushed his vessel up the east coast of Greenland to 77° north latitude, near Cape Bismarck, from which point he explored the territory northward to Independence Bay, thus completing the survey of the continent. But although he lost his life in the effort, his notes were complete and showed to the surprise of all that beyond the 78th parallel the coast trended northeast instead of northwest, extending towards Spitsbergen until the opening between the Arctic and Atlantic Oceans is narrowed to 240 miles, only one-third the width that had been formerly supposed to exist.

In the summer of 1909, both Frederick A. Cook and Robert E. Peary laid claims to having reached the north pole, both explorers claiming to have set out from the northern part of Grant Land, Cook in 1908 and Peary in 1909. Both

agree in their reports that there was smooth ice beyond the 88th parallel, in which rapid traveling could be accomplished, Peary alleging that he made the last 130 geographical miles in five forced marches, reaching the pole April 6, 1909. All was ice with no land in sight. Temperatures ranged from 12–° to –33° with cloudless sky. The return journey of 413 geographical miles was made in 16 days. A single imperfect sounding disclosed the existence of a deep ocean in close proximity to the pole. The reports of Cook, made previously to those of Peary, revealed almost identical conditions.

Among the most instructive observations upon the Greenland glaciers were those made in 1880 by Dr. N. O. Holst of the Swedish Geological Survey. These were made on the Frederickshaab Glacier in latitude 62° 32′, and have a most important bearing upon the mode of the accumulation of moraines of all sorts. He found extensive deposits of both englacial and subglacial drift, respectively characterized by angular and glaciated stones and bowlders. The largest accumulation of superglacial drift, which had been englacial, was observed on the southern edge of the lobe. The drift covering the ice-surface here, as exposed by the ablation or superficial melting, was ascertained to extend along a distance of nearly twelve miles, and to reach half a mile to a mile and a half upon the ice. The quantity and upper limit of the superglacial drift at this locality are given by him as follows:

> Its thickness is always greatest near land, but here it is often quite difficult to estimate its actual thickness, as it sometimes forms a compact covering, only in some fissures showing the underlying ice. This uneven thickness of moraine cover offers to the ice a proportionally varying protection against the sun. It thus happens that the unequal thawing moulds the underlying surface of the ice into valleys and hills, the latter sometimes arising to a height of fifty feet above the adjacent valley, and being so densely covered with morainic material that this completely hides the ice core, which, however, often forms the main part of the hill.

Farther in on the ice the moraine gradually thins out. At the locality just referred to the moraine cover, 3,000 feet from land, measured several inches in depth; still the ice was seen in some bare spots. Beyond 4,000 feet from land the moraine formed no continuous cover, and at 8,300 feet it ceased entirely, with a perceptible limit against clear ice. Only some scattered spots of sand and gravel were met with even a few hundred feet farther in on the ice.

The average thickness of the moraine taken across its entire width near its eastern end is estimated at from one to two feet. The limit between the moraine cover and the pure ice is always located at a considerable though varying elevation above the edge of the inland ice. In the instance of the above mentioned moraine it varied between 200 feet and 500 feet.

The ice within 100 feet of its borders invariably presents a slope towards the border, though generally not so steep as to render the ascent at all difficult. Farther in, the slope is much less marked, though there appears to exist a general rising towards the east, while the surface everywhere presents vast undulations. The border of the ice appears to have retreated quite recently in many places; in others it had evidently advanced . . . . On the surface the inland ice either presented the appearance of a compact mass of coarse crystallinic texture, reminding one of the grains of common rock candy, or else it is honeycombed by the solar heat and shows intersecting systems of parallel plates, apparently the remnants of large ice crystals, often several inches long, which have wasted away, only leaving the frame as it were, on which they were built. These plates or tablets are highly mirroring, reflecting the solar rays in all directions, depending on the position of each individual crystal.*

These observations respecting the height of the englacial till in the ice correspond closely to those of Professor Russell on the Malaspina Glacier in Alaska, and those of Professor

* "American Naturalist," vol. xxii. pp 589-598 and 705-713. July and August, 1888.

T. C. Chamberlin, hereafter to be noted, in northern Greenland.

Some most remarkable facts concerning the termination of numerous glaciers in northern Greenland and in Grinnell Land and Ellsmere Land on the other side of Smith Sound are reported by Professor Chamberlin and by General A. W. Greely.* In both these regions the glaciers often terminate in perpendicular, or projecting ice cliffs. So extensive and marked are these in Ellsmere Land that they were termed the "Chinese Wall." They extend across the country in an east and west direction and form an escarpment from 200 to 300 feet high. Over the crest of the wall appear the snow fields and snow covered mountains where the glacier has its source.

The explanation of this peculiar phenomenon is to be found partly in the fact that the upper strata of the ice move faster than the lower, tending to form a "breaker" in the ice, such as appears on the crest of an incoming wave. Partly also, as suggested by Professor Chamberlin, because the low angle at which the sun's rays strike the ice causes them to melt the lower dirt laden strata which attract the heat, faster than the purer strata found near the top of the ice.

*A. W. Greely, "Report of Proceedings of U. S. Expedition to Lady Franklin Bay," Washington, 1888, vol. i, pp. 274-296.

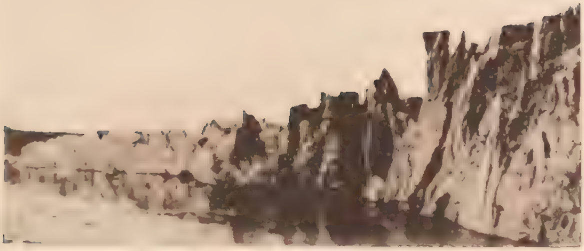

FIG. 34—Sea margin of Cornell Glacier, Greenland. (Tarr).

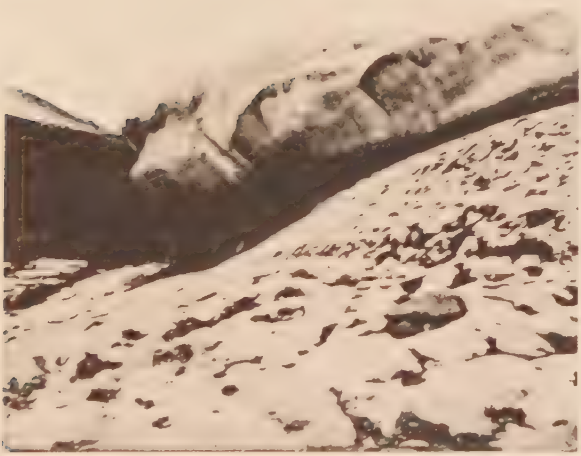

FIG. 35—Glacier in North Greenland, showing the upper strata of ice rolling over like breakers. (Photographed by Chamberlin)

CHAPTER V.

GLACIERS IN OTHER PARTS OF THE WORLD.

Before finally concentrating our attention upon the ancient glaciated area of North America, it will be profitable to take a glance at existing glaciers in other parts of the world. As is well known, glaciers still envelop the island of Spitzbergen and linger in the mountains of Norway and Sweden, of central Europe, and of southern Asia. Vast glaciers also come down to the sea-level in Patagonia, and appear higher up upon the mountains of southern Chili. The mountains of New Zealand * likewise contain numerous groups of glaciers nearly as extensive as those of the Alps. The so-called Antarctic Continent would seem to be covered with one vast sheet of ice pressing outward, and breaking off into immense icebergs.

The glaciers of the Alps have been so frequently described that only a few words need be devoted to them here. It is estimated that there are as many as four hundred glaciers in the Alpine range between Mont Blanc and Tyrol, and that, all told, they cover an area of more than 1,400 square miles. In many places the ice is estimated to be 600 feet in thickness. The Aletsch Glacier, in the Bernese Oberland, is the longest in the Alps, being not far from twenty miles. Many others are ten miles or more in length, and are often in certain portions of their course from one mile to one mile and a half wide. The line of perpetual snow in the Alps is something

* See Whitney's "Climatic Changes," pp. 269–274, to which we are largely indebted for the facts presented in this chapter.

more than 7,500 feet above the sea. The glaciers extend from 4,000 to 5,000 feet lower, though the limit is by no

FIG. 36.—Morteratsch Glacier, Grisons Alps. This glacier advances about seven inches per year. Centuries ago chalets stood a mile farther up the valley. In 1868 fragments of these ancient dwellings were washed out from underneath the ice.

means constant from year to year. "M. Forel reports, from the data which he has collected with much care, that there have been in this century five periods in the Alpine glaciers: of enlargement, from 1800 (?) to 1815; of diminution, from 1815 to 1830; of enlargement, from 1830 to 1845; of diminution, from 1845 to 1875; and of enlargement, again, from 1875 onward. He remarks further that these periods correspond with those deduced by Mr. C. Lang for the variations for the precipitations and temperature of the air; and, consequently, that the enlargement of the glaciers has gone for-

ward in the cold and rainy period, and the diminution in the warm and the dry ('Archives Sci. Phys. Nat.,' May 15, 1886, p. 503)." *

The glaciers of Scandinavia, with their snow-fields, are estimated to cover a space of about 5,000 square miles. The

FIG. 37.—The Svartisen Glacier on the west coast of Norway, just within the Arctic circle, at the head of a fiord ten miles from the ocean. Mouth of the glacier one mile wide, and a quarter of a mile back from the water. Terminal moraine in front. (Photographed by Dr. L. C. Warner.)

mountains are less lofty than the Alps, the greatest altitude being about 8,500 feet. But the more northern latitude and the moist climate are favorable to the production of glaciers. The largest single snow-field is that of Justedal, in latitude 62°, occupying a plateau about 5,000 feet above the sea-level, and an area of 580 square miles. From this plateau twenty-four glaciers descend through the gorges leading toward the North German Sea, the largest of which is about five miles long and three quarters of a mile wide. The Fondalen snow-field, in latitude 66° or 67°, is of nearly the same size with

* "American Journal of Science," vol. cxxxii, 1886, p. 77.

the preceding, and from it glaciers descend to the ocean-level. The Folgefon snow-field, still farther north, occupies an area of about one hundred square miles, from which three glaciers of about the same rank as the preceding descend to the sea.

To the north of the Scandinavian Peninsula the islands of Spitzbergen, Nova Zembla, and Franz-Josef Land, all lying above latitude 70°, and the latter north of latitude 80°, are deeply covered with glacial ice in their higher portions. Speaking of Magdalena Bay in Spitzbergen, Dr. G. Hartwig writes:

Four glaciers reach down this noble inlet: one, called the Wagon-Way, is 7,000 feet across at its terminal cliff, which is 300 feet high, presenting a magnificent wall of ice. But the whole scene is constructed on so colossal a scale that it is only on a near approach that the glaciers appear in all their imposing grandeur. . . . Besides the glaciers on Magdalena Bay, Spitzbergen has many others that protrude their crystal walls down to the water's edge; and yet but few icebergs, and the largest not to be compared with the productions of Baffin Bay, are drifted from the shores of Spitzbergen into the open sea. The reason is that the glaciers usually terminate where the sea is shallow, so that no very large mass if dislodged can float away, and they are at the same time so frequently dismembered by heavy swells that they can not attain any great size.*

The edge of the coast of the island of Franz-Josef Land is quite generally formed by the precipitous ends of glaciers a hundred feet or more in height and of unknown depth.

Iceland, too, has its glaciers in its more elevated portions, though nowhere do they come down to the sea level. The snow-field of Vatna Jokull, with an extreme elevation of 6,000 feet, has an area of 3,000 square miles. From recent reports it would seem that the glaciers of Iceland have for some time been rapidly advancing.

In Asia glaciers are found to a limited extent in the Caucasus Mountains, especially near the central portion of

* "Polar World," pp. 135, 136.

the range, where for a distance of 120 miles the average height is 12,000 feet, while several individual peaks rise higher than 16,000 feet. The snow-line in this range is from 11,000 to 12,000 feet above the sea-level, and in no case do the glaciers descend much lower than the 6,000-foot level. The Ural Mountains—owing probably to their being so narrow as not to afford space for large snow-fields—are entirely without glaciers. In Central Asia, however, where peaks in many cases rise upwards of 20,000 feet, glaciers appear on a grand scale in the Hindu Kush, the Tian Shan and the Altai mountains and in those surrounding the Pamir. While in the Himalayan range, about the head of the Indus, glaciers of great size are reported. That at the head of the Basha River "is over thirty miles in length, its lower part, for a distance of twenty or twenty-five miles, being about a mile and a half in width; above this—for some distance at least—it is still wider, a marked feature being its small inclination; along a large portion of its course it has an angle of slope of not over one and a half or two degrees.

"At the head of the Braldu Valley, an easterly tributary of the Shigar, is one of the largest known glaciers—that of Baltoro. This is said by the officers of the survey to be thirty-five miles in length, 'measured along a central line from its termination up to peak K[6].' The Biafo Glacier, the foot of which is about ten miles west of the Baltoro, is said to be over forty miles long." *

At the heads of the Sutlej and the Ganges similar glacial developments are witnessed, as well as at various other points throughout the whole length of the range.

Passing to South America, we find, according to the best reports, that until reaching the southern border of Chili glaciers are infrequent and relatively small. According to Mr. Whymper, no glaciers in Equador descend as low as 12,000 feet above the sea, and the glaciers in that region are largest on the eastern side. Only on Cotopaxi, Chimborazo, and Illin-

* Whitney's "Climatic Changes," pp. 284, 285.

issa are the glaciers comparable to those on Mont Blanc. In Chili, in the province of Colchagua, about latitude 35°, glaciers begin to appear, descending somewhat below the 6,000-foot level. "Proceeding southward from Colchagua, we pass into a region in which the climatic conditions are very different from those prevailing in the country farther north. The ranges border the sea very closely, the amount of precipitation increasing and becoming more generally distributed throughout the year. The temperature, at the same time diminishes, and all the conditions favorable to the formation of glaciers are found to prevail. In consequence of this, there is an extensive display of snow and ice along the southern coast of Chili, and especially at the very extremity of the continent."

"In Tierra del Fuego," writes Mr. Darwin, "the snowline descends very low, and the mountain sides are abrupt; therefore we might expect to find glaciers extending far down their flanks. Nevertheless, when on first beholding, in the middle of summer, many of the creeks on the northern side of the Beagle channel terminated by bold precipices of ice overhanging the salt water, I felt greatly astonished; for the mountains from which they descended were far from being very lofty." *

Darwin's observations upon the glaciers of South America are still standard, and are worthy of fuller reproduction. In his "Voyage of the Beagle" he says:

The descent of glaciers to the sea must, I conceive, mainly depend (subject, of course, to a proper supply of snow in the upper region) on the lowness of the line of perpetual snow on steep mountains near the coast. As the snow-line is so low in Tierra del Fuego, we might have expected that many of the glaciers would have reached the sea. Nevertheless, I was astonished when I first saw a range, only from 3,000 to 4,000 feet in height, in the latitude of Cumberland, with every valley filled with streams of ice descending to the sea-coast.

* Whitney's "Climatic Changes," pp. 272, 273.

Almost every arm of the sea which penetrates to the interior higher chain, not only in Tierra del Fuego, but also on the coast for 650 miles northward, is terminated by "tremendous and astonishing glaciers," as described by one of the officers on the survey. Great masses of ice frequently fall from these icy cliffs, and the crash reverberates, like the broadside of a man-of-war, through the lonely channels. These falls produce great waves, which break on the adjoining coasts. It is known that earthquakes frequently cause masses of earth to fall from sea-cliffs: how terrific, then, would be the effect of a severe shock (and such occur here) on a body like a glacier, already in motion, and traversed by fissures! I can readily believe that the water would be fairly beaten back out of the deepest channel, and then, returning with an overwhelming force, would whirl about huge masses of rock like so much chaff. In Eyre's Sound, in the latitude of Paris, there are immense glaciers, and yet the loftiest neighboring mountain is only 6,200 feet high. In this sound about fifty icebergs were seen at one time floating outward, and one of them must have been *at least* 168 feet in total height. Some of the icebergs were loaded with blocks of no inconsiderable size, of granite and other rocks, different from the clay-slate of the surrounding mountains. The glacier farthest from the pole, surveyed during the voyages of the Adventure and Beagle, is in latitude 46° 50′, in the Gulf of Penas. It is fifteen miles long, and in one part seven broad, and descends to the sea-coast. But even a few miles northward of this glacier, in the Laguna de San Rafael, some Spanish missionaries encountered "many icebergs, some great, some small, and others middle-sized," in a narrow arm of the sea, on the 22d of the month corresponding with our June, and in a latitude corresponding with that of the Lake of Geneva!

In Europe, the most southern glacier which comes down to the sea is met with, according to Von Buch, on the coast of Norway, in latitude 67°. Now, this is more than 20° of latitude, or 1,230 miles, nearer the pole than the Laguna de San Rafael. The position of the glaciers at this place and in the Gulf of Penas may be put even in a more striking point of view, for they descend to the sea-coast, within 7½° of latitude.

or 450 miles, of a harbor, where three species of oliva, a voluta, and a terebra are the commonest shells, within less than 9° from where palms grow, within 4½° of a region where the jaguar and puma range over the plains, less than 2½° from arborescent grasses, and (looking to the westward in the same hemisphere) less than 2° from orchidaceous parasites, and within a single degree of tree-ferns! *

Mr. Darwin's experience was so similar to that of those who visit Alaska (see Chapter III, page 50), that another extract will prove especially instructive by way of comparison. Speaking of the Straits of Magellan, he says:

The lofty mountains on the north side compose the granitic axis, or backbone of the country, and boldly rise to a height of between 3,000 and 4,000 feet, with one peak above 6,000 feet. They are covered by a wide mantle of perpetual snow, and numerous cascades pour their waters, through the woods, into the narrow channel below. In many parts, magnificent glaciers extend from the mountain-side to the water's edge. It is scarcely possible to imagine anything more beautiful than the beryl-like blue of these glaciers, and especially as contrasted with the dead white of the upper expanse of snow. The fragments which had fallen from the glacier into the water were floating away, and the channel, with its icebergs, presented for the space of a mile a miniature likeness of the Polar Sea. The boats being hauled on shore at our dinner-hour, we were admiring from the distance of half a mile a perpendicular cliff of ice, and were wishing that some more fragments would fall. At last down came a mass with a roaring noise, and immediately we saw the smooth outline of a wave traveling toward us. The men ran down as quickly as they could to the boats; for the chance of their being dashed to pieces was evident. One of the seamen just caught hold of the bows as the curling breaker reached it. He was knocked over and over, but not hurt; and the boats, though thrice lifted on high and let fall again, received no damage. This was most fortunate for us, for we were a hundred miles distant from the ship, and we

* "Voyage of the Beagle," edition of 1872, pp. 245–247.

should have been left without provisions or fire-arms. I had previously observed that some large fragments of rock on the beach had been lately displaced, but, until seeing this wave, I did not understand the cause. One side of the creek was formed by a spur of mica-slate; the head by a cliff of ice about forty feet high; and the other side by a promontory fifty feet high, built up of huge rounded fragments of granite and mica-slate, out of which old trees were growing. This promontory was evidently a moraine, heaped up at a period when the glacier had greater dimensions.*

Of the glaciers of New Zealand the following succinct account of Whitney must suffice:

On the western coast of the southern island, between the parallels of 42° and 45°, rises abruptly from the sea a grand range of mountains, the culminating point of which, Mount Cook, is about 13,000 feet in elevation. Along this chain, for a length of about one hundred miles, are developed numerous groups of glaciers, some of which are not much inferior in size to the largest of those of the Alps. The Tasman Glacier is said by Haast, who first scientifically explored and described these mountains, to be ten miles in length and a mile and three quarters broad at its termination, the lower portion, for a distance of three miles, being covered with morainic detritus.†

Glacial conditions prevail over the Antarctic Continent. Icebergs of great size are frequently encountered up to 58° south latitude, in the direction of Cape Horn, and as far as latitude 33° in the direction of Cape of Good Hope. The number and size of these, of which more particulars will be given presently, are such as to necessitate an extensive area of glaciers about the south pole. Much of all that is known of the Antarctic Continent was discovered by Sir J. C. Ross during the period extending from 1839 to 1843, when, between the parallels of 70° and 78° south latitude, he en-

* "Voyage of the Beagle," edition of 1872, pp. 224, 225.

† "Climatic Changes," pp. 273, 274.

countered in his explorations a precipitous mountain-coast, rising from 7,000 to 10,000 feet above tide. Through the valleys intervening between the mountain-ranges huge glaciers descended, and "projected in many places several miles into the sea, and terminated in lofty perpendicular cliffs. In a few places the rocks broke through their icy covering, by which alone we could be assured that land formed the nucleus of this, to appearance, enormous iceberg." *

Again, speaking of the region in the vicinity of the lofty volcanoes Terror and Erebus, between 10,000 and 12,000 feet high, the same navigator says:

"We perceived a low white line extending from its extreme eastern point as far as the eye could discern to the eastward. It presented an extraordinary appearance, gradually increasing in height as we got nearer to it, and proving at length to be a perpendicular cliff of ice, between 150 and 200 feet above the level of the sea, perfectly flat and level at the top, and without any fissures or promontories on its even seaward face. What was beyond it we could not imagine; for, being much higher than our mast-head, we could not see anything except the summit of a lofty range of mountains extending to the southward as far as the seventy-ninth degree of latitude. These mountains, being the southernmost land hitherto discovered, I felt great satisfaction in naming after Sir Edward Parry. . . . Whether Parry Mountains again take an easterly trending and form the base to which this extraordinary mass of ice is attached, must be left for future navigators to determine. If there be land to the southward, it must be very remote, or of much less elevation than any other part of the coast we have seen, or it would have appeared above the barrier."

This ice-cliff or barrier was followed by Captain Ross as far as 198° west longitude, and found to preserve very much the same character during the whole of that distance. On the lithographic view of this great ice-sheet given in Ross's work it is described as "part of the South Polar Barrier, to 180

* Quoted by Whitney in "Climatic Changes," p. 314.

feet above the sea-level, 1,000 feet thick, and 450 miles in length."

A similar vertical wall of ice was seen by D'Urville, off the coast of Adelie Land. He thus describes it: "Its appearance was astonishing. We perceived a cliff having a uniform elevation of from 100 to 150 feet, forming a long line extending off to the west. . . . Thus for more than twelve hours we had followed this wall of ice, and found its sides everywhere perfectly vertical and its summit horizontal. Not the smallest irregularity, not the most inconsiderable elevation, broke its uniformity, for the twenty leagues of distance which we followed it during the day, although we passed it occasionally at a distance of only two or three miles, so that we could make out with ease its smallest irregularities. Some large pieces of ice were lying along the side of this frozen coast; but, on the whole, there was open sea in the offing." *

In addition to the recent direct observations upon the glaciers of the Antarctic Continent, we are permitted to turn to an important source of indirect evidence furnished by the icebergs encountered in the region. Many of these are of such size as to indicate an enormous depth to the glacial ice of which they are fragments, and imply the existence of a glaciated area larger even than Greenland. In reading the accounts of icebergs we should bear in mind that the specific gravity of ice is such that where there is one cubic foot of an iceberg above the water's surface there are seven or eight cubic feet below the surface; so that, if the form of the berg could be supposed to be symmetrical, we should multiply the height of the berg above water by eight or nine to get its perpendicular dimension. But as the forms of the icebergs are usually irregular, this rule can not always be applied. In several of the instances to be referred to, however, the masses are so large, and the forms so regular, that we can not be far amiss in applying the rule. Some of these masses of floating ice are of almost incredible size, and their

* Quoted by Whitney in "Climatic Changes," pp. 315, 316.

origin can only have been upon large surfaces of land in every way favorably situated for the accumulation of snow and the formation of glaciers. The following are a few of the examples reported a century ago by Captain Cook :

At eight o'clock saw an island of ice to the westward of us, being then in the latitude of 50° 40′ south, and longitude 2° 0′ east of the Cape of Good Hope. Soon after, the wind moderated, and we let all the reefs out of the top-sails, got the sprit-sail-yard out, and top-gallant-mast up. The weather coming hazy, I called the Adventure by signal under my stern ; which was no sooner done, than the haze increased so much, with snow and sleet, that we did not see an island of ice, which we were steering directly for, till we were less than a mile from it. I judged it to be about fifty feet high, and half a mile in circuit. It was flat at the top, and its sides rose in a perpendicular direction, against which the sea broke exceedingly high. . . .

At one o'clock we steered for an island of ice, thinking, if there were any loose ice round it, to take some on board, and convert it into fresh water. At four we brought to, close under the lee of the island ; where we did not find what we wanted, but saw upon it eighty-six penguins. This piece of ice was about half a mile in circuit and one hundred feet high and upward, for we lay for some minutes with every sail becalmed under it. . . .

At nine in the morning we bore down to an island of ice which we reached by noon. It was full half a mile in circuit, and two hundred feet high at least, though very little loose ice about it. But while we were considering whether or not we should hoist out our boats to take some up, a great quantity broke from the island. Upon this we hoisted out our boats, and went to work to get some on board. The pieces of ice, both great and small, which broke from the island, I observed, drifted fast to the westward ; that is, they left the island in that direction, and were, in a few hours, spread over a large space of sea. . . .

Finding here a good quantity of loose ice, I ordered two boats out, and sent them to take some on board. While this

was doing, the island, which was not less than half a mile in circuit, and three or four hundred feet high above the surface

FIG. 38.—Iceberg.

of the sea, turned nearly bottom up. Its height, by this circumstance, was neither increased nor diminished apparently. . . .

In the evening we had three islands of ice in sight, all of them large; especially one, which was larger than any we had yet seen. The side opposed to us seemed to be a mile in extent; if so, it could not be less than three in circuit. As we passed it in the night, a continual cracking was heard, occasioned, no doubt, by pieces breaking from it. For, on the morning of the 6th, the sea, for some distance round it, was covered with large and small pieces; and the island itself did not appear so large as it had done the evening before. It could not be less than one hundred feet high; yet such was the impetuous force and height of the waves which were broken against it, by meeting with such a sudden resistance, that they rose considerably higher.*

For a series of years the Board of Trade in England collected statistics from the navigators of the Southern Ocean who reported icebergs encountered in their voyages. From

* "Voyage round the World," pp. 20, 29, 48–50, 54.

these reports, and from a paper of Mr. Towson upon the subject, published by the Board of Trade, Mr. Croll makes the following collection of facts concerning them, premising that, "with one or two exceptions, the heights of the bergs were accurately determined by angular measurement":

September 10, 1856.—The Lightning when in latitude 55° 33′ south, longitude 140° west, met with an iceberg 420 feet high.

November, 1839.—In latitude 41° south, longitude 87° 30′ east, numerous icebergs 400 feet high were met with.

September, 1840.—In latitude 37° south, longitude 15° east, an iceberg 1,000 feet long and 400 feet high was met with.

February, 1860.—Captain Clark, of the Lightning, when in latitude 55° 20′ south, longitude 122° 45′ west, found an iceberg 500 feet high and three miles long.

December 1, 1859.—An iceberg, 580 feet high, and from two and a half to three miles long, was seen by Captain Smithers, of the Edmond, in latitude 50° 52′ south, longitude 43° 58′ west. So strongly did this iceberg resemble land that Captain Smithers believed it to be an island, and reported it as such, but there is little or no doubt that it was in reality an iceberg. There were pieces of drift-ice under its lee.

November, 1856.—Three large icebergs, 500 feet high, were found in latitude 41° 0′ south, longitude 42° 0′ east.

January, 1861.—Five icebergs, one 500 feet high, were met with in latitude 55° 46′ south, longitude 155° 56′ west.

January, 1861.—In latitude 56° 10′ south, longitude 160° 0′ west, an iceberg 500 feet high and half a mile long was found.

January, 1867.—The bark Scout, from the west coast of America, on her way to Liverpool, passed some icebergs 600 feet in height and of great length.

April, 1864.—The Royal Standard came in collision with an iceberg 600 feet in height.

December, 1856.—Four large icebergs, one of them 700 feet high, and another 500 feet, were met with in latitude 50° 14′ south, longitude 42° 54′ east.

December 25, 1861.—The Queen of Nations fell in with an iceberg in latitude 53° 45′ south, longitude 170° 0′ west, 720 feet high.

December, 1856.—Captain P. Wakem, ship Ellen Radford, found, in latitude 52° 31′ south, longitude 43° 43′ west, two large icebergs, one at least 800 feet high.

Mr. Towson states that one of our most celebrated and talented naval surveyors informed him that he had seen icebergs in the southern regions 800 feet high.

March 23, 1855.—The Agneta passed an iceberg in latitude 53° 14′ south, longitude 14° 41′ east, 960 feet in height.

August 16, 1840.—The Dutch ship, General Baron von Geen, passed an iceberg 1,000 feet high in latitude 37° 32′ south, longitude 14° 10′ east.

May 15, 1859.—The Roseworth found, in latitude 53° 40′ south, longitude 123° 17′ west, an iceberg as large as "Tristan d'Acunha." *

Upon these facts Mr. Croll remarks:

In the regions where most of these icebergs were met with, the mean density of the sea is about 1·0256. The density of ice is ·92. The density of icebergs to that of the sea is therefore as 1 to 1·115; consequently, every foot of ice above water indicates 8·7 feet below water. It therefore follows that those icebergs 400 feet high had 3,480 feet under water—3,880 feet would consequently be the total thickness of the ice. The icebergs which were 500 feet high would be 4,850 feet thick, those 600 feet high would have a total thickness of 5,820 feet, and those 700 feet high would be no less than 6,790 feet thick, which is more than a mile and a quarter. The iceberg 960 feet high, sighted by the Agneta, would be actually 9,312 feet thick, which is upward of a mile and three quarters.

Although the mass of an iceberg below water compared to that above may be taken to be about 8·7 to 1, yet it would not be always safe to conclude that the thickness of the ice below water bears the same proportion to its height above. If the berg, for example, be much broader at its base than at its

* "Climate and Time," pp. 382–385.

top, the thickness of the ice below water would bear a less proportion to the height above water than as 8·7 to 1. But a berg, such as that recorded by Captain Clark, 500 feet high and three miles long, must have had only 1 to 8·7 of its total thickness

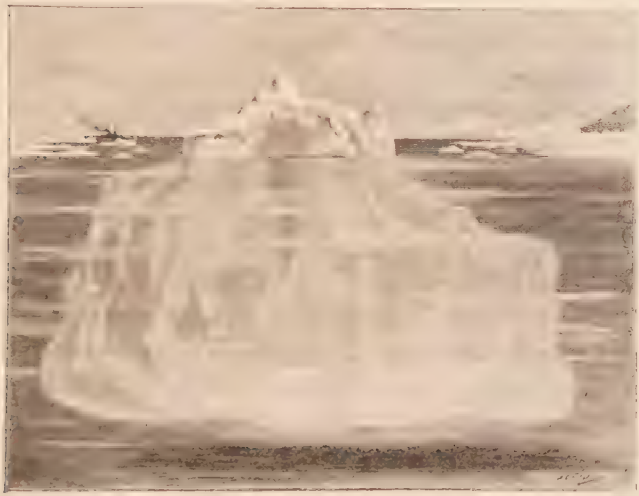

Fig. 39.—Floating berg, showing the proportions above and under the water

above water. The same remark applies also to the one seen by Captain Smithers, which was 580 feet high, and so large that it was taken for an island. This berg must have been 5,628 feet in thickness. The enormous berg which came in collision with the Royal Standard must have been 5,820 feet thick. It is not stated what length the icebergs 730, 960, and 1,000 feet high respectively were; but supposing that we make considerable allowance for the possibility that the proportionate thickness of ice below water to that above may have been less than as 8·7 to 1, still we can hardly avoid the conclusion that the icebergs were considerably above a mile in thickness. But if there are icebergs above a mile in thickness, then there must be land-ice somewhere on the southern hemisphere of that thickness. In short, the great antarctic ice-cap must in some places be over a mile in thickness at its edge.

Interest in Antarctic exploration did not revive until the beginning of the present century, but since then it has been very active. In 1901 Captain Scott of the English navy set out in the vessel *Discovery* and, during the following year, reached a point within 670 miles of the south pole, 100 miles nearer than anyone had been before.

On August 7, 1907, Lieut. Ernest Shackelton, of the English navy sailed from Plymouth for the purpose of reaching the south pole. On January 6, 1909, his party reached a point within ninety-three geographical miles of the pole and then was compelled to turn back. Here they were on a plateau between 10,000 and 11,000 feet above sea-level, which seemed to stretch unbroken southward as far as their glass could extend their vision, thus revealing conditions very different from those about the north pole, where there is a sea several thousand feet deep covered with drifting ice.

According to Lieutenant Shackelton, "We now know that the Great Southern Ice Barrier is bounded by mountains running in a southeasterly direction from 78° south at least, and that an immense glacier leads to a plateau over 10,000 feet above the sea level, on which is situated the geographical south pole.

"Numerous inland mountains have been discovered, and specimens of rock from them show that at some period in the geological history of the earth a warm climate prevailed in these ice bound regions."

"The discovery of microscopical life in the frozen lakes is extremely interesting. The scientists of the expedition demonstrated that the tiny rotifers could exist in a temperature of 100° of frost, and also emerge unscathed from the test of a temperature of 200°F. . . . . Strange as it may seem, there is a large marine fauna in the icy waters of the Antarctic. The temperature of the sea in those regions varies but little in winter and summer, and this fact is conducive to an abundant marine life."

Among the most important discoveries was that of the South Magnetic Pole. Leaving their winter quarters on October 5th, they traveled westward amid great difficulties and dangers 250 miles along the coast on the sea ice, "relaying" the whole distance. As the summer advanced they began to suffer from the heat, and although they were traveling over ice they often had to divest themselves of their outer garments. On the 16th of December they left the shore and struck inland in the direction of the Magnetic Pole, which they estimated to be about 200 miles distant. During this journey they encountered, though in the midst of summer, a heavy snowfall and a succession of blizzards extending through a fortnight. They also, like the southern party had to ascend a high plateau and found the ice covering to be a perfect maze of crevasses, which rendered travel almost impossible. Following the magnetic meridian, and ascending a succession of terraces, they at length reached an undulating snow plain 7,000 or 8,000 feet above sea-level, where the traveling was easier, and on the 16th of January reached the object of their search in latitude 72° 45′ south, longitude 145.° Here they hoisted the Union Jack and claimed the land in the name of his Majesty the King of England. The cold at this elevation was intense, and there was a continual ice wind from the southwest, with a succession of blizzards. Hoisting a sail and thus taking advantage of this wind the party reached their depot on the 3d of February in a state of semi-starvation.

CHAPTER VI.

SIGNS OF FORMER GLACIATION.

Before attempting to delineate the exact southern boundary of the ice during the height of the Glacial period in North America, it will be necessary briefly to discuss the evidence upon which the inferences concerning the Glacial period are based. The reader will ask: How is it possible to determine, with any reasonable degree of accuracy, the extent of the region formerly covered by glacial ice, but which has been free from such covering for many thousand years, and during all that time has been subjected to the disintegrating and modifying influences connected with the ceaseless operation of the ordinary forces of Nature?

The consideration of this question will introduce us not only to some of the most interesting problems of this particular subject, but to some of the fundamental principles underlying all inductive reasoning. The study of the great Ice age, like all other branches of geology, deals with the effects of past causes. From the marks which have been left upon the surface of the earth, we endeavor by scientific processes to reproduce to our imagination the condition of things which would account for these marks. As reasonable beings, we are compelled to bring into the field of thought a past cause sufficient to produce all the results observed, both positive and negative; and when our imagination has found an *adequate* cause, true science compels us to rest with that.

From observation upon living glaciers, and from the known nature of ice, we may learn to recognize the track

of a glacier as readily and unmistakably as we would the familiar foot-prints of an animal. The indications upon which glacialists have depended for their information as to the extent of the glaciated region during the great Ice age are of three kinds: 1. Grooves and scratches preserved upon the rocks in place and upon the bowlders and pebbles shoved along under the ice. 2. The extensive unstratified deposits called "till," which are traceable to glacial action. 3. Transported material found in such positions that it must have been left by glacial ice rather than floating ice.

In respect of the nature of ice we are compelled to admit that it is capable of motion like such semi-fluids as cool-

FIG. 40.—Scratched stone from the till of Boston. Natural size about one foot and a half long by ten inches wide. (From photograph.)

ing pitch or lava. But, though it does move, it is not capable of adapting itself so perfectly as a real fluid to the

FIG. 41.—Glacial striæ and semi-lunar marks on Berea sandstone, Amherst, Ohio, five miles south of Lake Erie. Direction nearly north by south. Top of page south. Distance between semi-lunar marks about two and a half feet. (From photograph by Chamberlin.)

inequalities of the country. From this comparatively solid character of ice certain important results must follow. It is easy to see that the stones of all sizes, while being dragged along underneath the ice, would be held in a comparatively firm grasp so as to be polished and striated and scratched in a peculiar manner. On the shores of bays and lakes and in bottoms of streams we find that the stones are polished and rounded in a symmetrical manner, but are never scratched. The mobility of water is such that the edges and corners of the stones are rubbed together by a force acting successively in every possible direction. But in and under the ice the firm grasp of the stiff semi-fluid causes the stony fragments to move in a nearly uniform direction, so that they grate over the underlying rocks like a rasp, wearing down the rocks beneath and slowly grinding them to powder, and, at the same time, being worn themselves in the process. From the stability of the motion of such a substance as ice there would, from the nature of the case, result groovings and striation both on the rocks beneath and on the bowlders and pebbles which, like iron plowshares, are forced over them. Scratched surfaces of rock and scratched stones are therefore, in ordinary cases, most trustworthy indications of glacial action. The direction of the scratches upon these glaciated bowlders and pebbles is, also, worthy of notice. The scratches upon the loose pebbles are mainly in the direction of their longest diameter—a result which follows from a mechanical principle, that bodies forced to move through a resisting medium must swing around so as to proceed in the line of least resistance. Hence the longest diameter of such moving bodies will tend to come in line with the direction of the motion.

A scratched surface is, however, not an infallible proof of the former presence of a glacier where such a surface is found, or, indeed, of glacial action at all. A stone scratched by glacial forces may float away upon an iceberg, and be deposited at a great distance from its home. Indeed, icebergs and shore-ice may produce, in limited degree, the phe-

nomena of striation which we have just described. One can but admire the enthusiasm with which the old defenders of the iceberg theory dwelt upon the capacity of icebergs and shore-ice to polish, groove, and scratch the surfaces over which they moved. Sir Charles Lyell tells us, in the account of his first visit to America, how he stood at the foot of a cliff at Cape Blomidon, Nova Scotia, transfixed at the sight of recent furrows which were the exact counterpart of the grooves of ancient date which he had elsewhere described. So extensive were these, that they seemed for the moment to render the glacial theory unnecessary:

As I was strolling along the beach at the base of these basaltic cliffs, collecting minerals, and occasionally recent shells at low tide, I stopped short at the sight of an unexpected phenomenon. The solitary inhabitant of a desert island could scarcely have been more startled by a human foot-print in the sand, than I was on beholding some recent furrows on a ledge of sandstone under my feet, the exact counterpart of those grooves of ancient date which I have so often described in this work, and attributed to glacial action. After having searched in vain at Quebec for such indications of a modern date, I had despaired of witnessing any in this part of the world. I was now satisfied that, whatever might be their origin, those before me were quite recent.

The inferior beds of soft sandstone which are exposed at low water at the base of the cliff at Cape Blomidon, form a broad ledge of bare rock, to the surface of which no sea-weed or barnacles can attach themselves, as the stone is always wearing away slowly by the continual passage of sand and gravel, washed over it from the talus of fallen fragments which lies at the foot of the cliff on the beach above. The slow but constant undermining of the perpendicular cliff forming this promontory, round which the powerful currents caused by the tide sweep backward and forward with prodigious velocity, must satisfy every geologist that the denudation by which the ledge in question has been exposed to view is of modern date. Whether the rocks forming the cliff extended so far as the water's edge, ten, fifty, or one hundred years ago, I have no

means of estimating; but the exact date and rate of destruction are immaterial. On this recently-formed ledge I saw several straight furrows half an inch broad, some of them very nearly parallel, others diverging, the direction of the former being north 35° east, or corresponding to that of the shore at this point. After walking about a quarter of a mile, I found another set of similar furrows, having the same general direction within five degrees; and I made up my mind that, if these grooves could not be referred to the modern instrumentality of ice, it would throw no small doubt on the glacial hypothesis. When I asked my guide—a peasant of the neighborhood—whether he had ever seen much ice on the spot where we stood, the heat was so excessive (for we were in the latitude of the south of France, 45° north), that I seemed to be putting a strange question. He replied that, in the preceding winter of 1841, he had seen the ice, in spite of the tide, which ran at the rate of ten miles an hour, extending in one uninterrupted mass from the shore where we stood to the opposite coast at Parrsborough, and that the icy blocks, heaped on each other, and frozen together or "packed" at the foot of Cape Blomidon, were often fifteen feet thick, and were pushed along, when the tide rose, over the sandstone ledges. He also stated that fragments of the "black stone" which fell from the summit of the cliff, a pile of which lay at its base, were often frozen into the ice, and moved along with it. I then examined these fallen blocks of amygdaloid scattered around me, and observed in them numerous geodes coated with quartz-crystals. I have no doubt that the hardness of these gravers, firmly fixed in masses of ice, which, although only fifteen feet thick, are often of considerable horizontal extent, have furnished sufficient pressure and mechanical power to groove the ledge of soft sandstone.*

Stones are also striated by other agencies than moving ice. Extensive avalanches and land slides furnish conditions analogous to those of a glacier, and might in limited and favorable localities simulate its results. In those larger geological

* "Travels in America," first series, vol. ii, pp. 144–146.

FIG. 42.– Cut in till overlaid by a stratified deposit on Seven Mile Creek, near Hamilton, in southern Ohio. Height of section about thirty feet. The lower twenty feet is unstratified and full of scratched stones. The glacial floods deposited the stratified material at the close of the Ice Age. The creek has since eroded its present trough. (From a photograph of the United States Geological Survey by Wright.)

movements, also, where the crust of the earth is broken and the edges of successive strata are shoved over each other, a species of striation is produced which in technical terms is called a *slickenside*. Occasionally this deceives the inexperienced or incautious observer. But by due pains all these semblances may be detected and eliminated from the problem, leaving a sufficient number of unquestionable phenomena due to true glacial action.

A second indubitable mark of glacial action is found in the character of the deposit left after the retreat of the ice. Ice and water differ so much from each other in the extent of their fluidity, that ordinarily there is little danger of confusing the deposits made by them. A simple water deposit is inevitably stratified. The coarse and fine material can not be deposited by water alone, simultaneously in the same place. Along the shores of large bodies of water the deposits of solid material are arranged in successive parallel lines, the material growing finer and finer as the lines recede from the shore. The force of the waves is such in shallow water that they move pebbles of considerable size. Indeed, where the waves strike against the shore itself, vast masses of rock are oftentimes moved by the surf. But, as deeper water is reached, the force of the waves becomes less and less at the bottom, and so the transported material is correspondingly fine, until, at the depth of about seventy feet, the force of the waves is entirely lost; and beyond that line nothing will be deposited but fine mud, the particles of which are for a long while held in suspension before they settle.

In the deltas of rivers, also, the sifting power of water may be observed. Where a mountain-stream first debouches upon a plain, the force of its current is such as to move large pebbles, or bowlders even, two or three feet in diameter. But, as the current is checked, the particles moved by it become smaller and smaller until in the head of the bay, or in the broad current of the river which it enters, only the finest sediment is transported. The difference between the size of material transported by the same stream when in flood and

when at low water is very great, and is the main agent in producing the familiar phenomena of stratification. During the time of a flood vast bodies of pebbles, gravel, and sand are pushed out by the torrent over the head of the bay or delta into which it pours; while during the lower stages of water only fine material is transported to the same distance; and this is deposited as a thin film over the previous coarse deposit. Upon the repetition of the flood another layer of coarser material is spread over the surface; and so, in successive stages, is built up in all the deltas of our great rivers a series of stratified deposits. In ordinary circumstances it is impossible that coarse and fine material should be intermingled in a water deposit without stratification. Water moving with various degrees of velocity is the most perfect sieve imaginable; so that a water deposit is of necessity stratified.

To this general principle, however, exception must be made in the case of accumulations taking place slowly in deep water containing icebergs from which bowlders and pebbles may be dropped. These, of course, will be found distributed through the fine deposit without stratification. It is thought by President Chamberlin,* however, that in cases where the bowlders dropped from the icebergs are of marked irregularity in their configuration, their position in the ooze at the bottom would betray their origin. Flattish stones, in falling through the water, would often descend edgewise, and would not uniformly lie in the mud upon their flat surface. I have myself observed numerous places in southern Ohio where the arrangement of the limestone fragments abundantly illustrates and confirms this theory. The horizontal position of such fragments in the clay of that region seems to show that they were arranged in the deposit by a moving ice-sheet, and were not dropped from floating ice.

It is evident that ice is so nearly a solid that the earthy material deposited by it must be unassorted. The mud, sand, gravel, pebbles, and bowlders, dragged along underneath a

* "Terminal Moraine of the Second Glacial Epoch," p. 297.

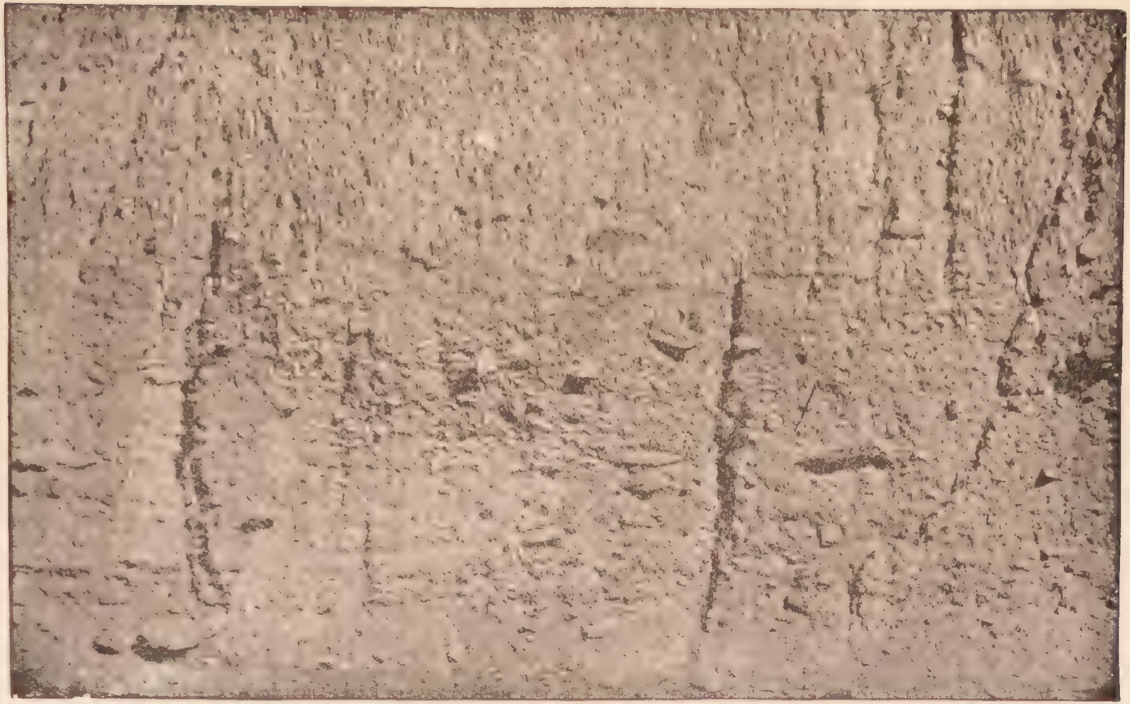

FIG. [illegible]. Perpendicular section of till on Seven Mile Creek, near the preceding, showing the horizontal arrangement of the flat fragments of limestone (see text). Height about fifteen feet. (From a photograph of the United States Geological Survey by Wright.)

moving stream of ice, must be left in an unstratified condition—the coarse and the fine being indiscriminately mingled together. Now, this is the character of the extensive deposits of loose material which cover what we designate as the glaciated region. It is true that over this region there are extensive stratified deposits. But these invariably mark the situation of abandoned lakes and water-courses. To these interesting formations a special chapter will be devoted. But the larger part of the region marked upon the map as glaciated is covered with an unstratified deposit, in which are mingled a variety of materials derived from rocks both of the locality and of far-distant regions. Moreover, the pebbles in this deposit are the most of them polished and scratched after the manner of those which we know to have been subjected to glacial action. Ordinarily there can be no question of the glacial character of this formation, even when no considerations are taken into account except those which appear in the deposit itself. Still, in certain situations, floating ice may transport coarse material, and drop it in the midst of finer silt, so as closely to simulate a true unstratified deposit. In the majority of cases, however, the configuration of the country is such as to exclude the agency of floating ice from the problem.

We come, therefore, in the third place, to a mass of recently discovered facts which would seem to place the glacial theory above all question. When once the limit of these unstratified deposits, containing striated stones and transported material, had been accurately determined, it was found that the margin was exceedingly irregular in two respects. The southern edge of this deposit is both *serrate* and *crenate*—that is, it does not follow a straight east-and-west line, but in places withdraws to the north, and in others extends in lobe-shaped projections far to the south. This constitutes its serrate character. But it is the crenate character of its southern border which is of most significance. The southern border, with its indentations and projections, is not determined by any natural barrier. The southern

boundary-line rises from the level of the sea at New York to the height of the Blue Mountains in New Jersey, and descends into the valley of the Delaware, and rises again over the Blue Ridge in Pennsylvania, crossing the valley between it and Pocono Mountain, where it runs for many miles at an elevation of 2,000 feet above the sea, and descends in a nearly straight line to the East Branch of the Susquehanna at Beach Haven, where it is not more than 500 feet above the sea. Thence it continues onward in a diagonal course across the Alleghanies, with their various subsidiary valleys, to its great turning-point in southwestern New York. Thence to the trough of the Mississippi, for a distance of 700 or 800 miles, the line winds gradually down the western flanks of the Alleghanies, paying little attention in its deflections to the minor inequalities of the country. West of the Mississippi the rise is equally gradual to northern Dakota and Montana, where the glacial border is 2,000 or 3,000, and in British America 4,000, feet above the sea.

Thus it is not possible, by the supposition of any conceivable submergence, to account for this line of demarkation. Water which would have floated ice from the north to almost any point along that line would have floated it farther south. Consequently, the line must have been determined not by a barrier which restrained a fluid, but by the irregular losses of momentum such as would take place in a semi fluid moving in the line of least resistance from various central points of accumulation.

The reader will find the subject of this chapter treated with great fullness by President Chamberlin in the "Third Annual Report of the United States Geological Survey," pp. 291–402, and in the "Seventh Report," pp. 149–248, where the subject of rock-scoring is most fully illustrated. Numerous illustrations in the present volume have been reserved for the latter part of Chapter X, on "Glacial Erosion and Transportation," which the reader will do well to consult in this connection as well as in the order in which it occurs.

CHAPTER VII.

BOUNDARY OF THE GLACIATED AREA IN NORTH AMERICA.

DOUBTLESS the Ice age both began and ended in a great number of local glaciers which became confluent and continuous only during the middle of the period. One of the most interesting evidences of the independent movement of the different portions of the great North American ice-sheet is to be found in the driftless region of southwestern Wisconsin. Here is an area of several hundred square miles in extent, occupying more or less of the adjoining area in Illinois, Iowa, and Minnesota, which remained as an island in the great continental expanse of ice. The ice moved past it upon both sides, and then closed together upon the south, and moved onward, a distance of about 300 miles, to the vicinity of St. Louis.

When, in the year 1876, attention was first directed by Mr. Clarence King,* Mr. Warren Upham,† and Professor George H. Cook ‡ to the terminal moraines of southern New England and northern New Jersey, by President T. C. Chamberlin # to the character and connection of the kettle-moraine in Wisconsin, and by Dr. George M. Dawson ‖ to the

* See my paper in the "Proceedings of the Boston Society of Natural History," vol. xix, pp. 60–63.

† "New Hampshire Geological Report," vol. iii, pp. 300–305.

‡ "Report upon the Geology of New Jersey for 1878."

\# "On the Extent and Significance of the Wisconsin Kettle-Moraine."

‖ "On the Superficial Geology of the Central Region of North America," from the "Quarterly Journal of the Geological Society," vol. xxxi, 1875. This is a summary of a portion of the author's "Report on the Geology and Resources of the Forty-ninth Parallel," 1875.

significance of the extension of the Missouri coteau in British America, hopes were at once raised that a distinct line of terminal moraines might be traced across the continent. With this theory in mind, the late Professor H. Carvill Lewis and myself began the survey of Pennsylvania in 1881. But, upon crossing the Alleghanies and pursuing the investigations in the Mississippi Valley, I was compelled to abandon this view, and to be content with finding marginal deposits more evenly spread over the country, ending, in some cases, in an extremely attenuated border. And, upon reflection, the fallacy in our original theory, that there must be a *terminal moraine*—that is, a noticeable ridge of glacial accumulations to mark the farthest extent of the ice—is easily seen.

The extent of a glacial deposit at any particular point will be determined by three factors, namely: 1. The amount of accessible loose material in the line of glacial movement which the ice can seize upon and transport. It is evident that, if the rocks over which the ice moves are hard and smooth and already denuded of loose material, there may be much motion of ice with little transportation of soil. 2. The length of time during which the ice-front remains at a given point, since time acts as a multiplier. 3. The exemption of the deposit from the action of denuding agencies. When a glacier melts, the torrents of water arising may, in a short time, tear down and distribute as sediment to distant valleys the material accumulated by the slow movement of centuries. Indeed, it has been questioned by some whether the larger part of the grist of the glacier has not been thus transported far beyond the extreme limits reached by the ice itself. This transportation by water from the front of glaciers is certainly of immense extent. Every subglacial stream is surcharged and milky-white with sediment as it emerges from the ice-front. As before stated, a traveler in the State of Washington, from Portland to Seattle, can detect the presence of glaciers in the Cascade Mountains, scores of miles away, simply by the milky color of

the streams crossed by the railroad. At Tacoma, on Puget Sound, the milk-white water, coming down from distant glaciers in Mount Tacoma, struggles with the dark-blue water of the sound for the occupancy of the harbor, and gives the surface of the bay the nondescript appearance of an immense slice of marble-cake. As one passes the mouth of the Stickeen River beyond Fort Wrangel, in Alaska, the line of demarkation between the clear waters of the ocean and those of the glacier-laden currents of the river is as plain as that between the water itself and the shore. One of the most interesting occupations of the leisure hours of our long encampment in Glacier Bay was to watch this struggle for occupancy between the milk-white water of the four subglacial streams pouring into the inlet, and the pure blue waves urged against it by the recurring tides of the ocean. With a rising tide of twenty-two feet, the line of demarkation between the glacial water and the waters from the Pacific moved alternately backward and forward over the inlet for a distance of one or two miles, and in the shallow water, miles away, the screw of the steamer brought to the surface great quantities of the sediment which is rapidly filling up the bay.

When one considers the constancy of the operation of this cause during all glacial time, he may well be pardoned for regarding the glacial *débris* still remaining upon the continent as but an insignificant remnant of the total amount transported and deposited by glacial action. During the whole continuance of the Glacial period in North America, subglacial streams must have sent their turbid currents down through every New England outlet, and through the Hudson, the Delaware, the Susquehanna, and all the northern tributaries of the Mississippi. The terraces marking these glacial water-courses retain simply a part of the coarser material transported; the fine material went constantly onward to the sea, helping to build up the immense delta of the lower Mississippi, and to line the whole coast of the Atlantic with a deposit of fine sediment ready at some day to rise above the surface as fruitful soil.

With these remarks, we are prepared to come to the specific subject of the present chapter, namely, the character and extent of the glacial deposits marking the southern border of the glaciated area in North America. Through a portion of the distance these accumulations are so marked as to merit the name of *terminal moraines*. Through another portion that name is hardly applicable to anything near the glacial border. In a subsequent chapter there will be a distinct discussion of the whole question of moraines. In this it is our purpose to follow somewhat minutely the boundary of the area, and detail its various aspects.

Off the coast of Maine the ice, at its culminating period, extended an unknown distance into the sea, surmounting the eminences of Mount Desert and all that rock-bound coast, and leaving its terminal deposits in water so deep that there is little hope of ever determining its exact situation. But in southeastern Massachusetts the deposits emerge from the water as true moraines, and offer themselves as most interesting objects of study. Nantucket, Tuckernuck, Chappaquiddick, Martha's Vineyard, No Man's Land, and Block Island are but portions of the extreme terminal moraine whose back emerges at these points from the water. Cape Cod, from Provincetown to Wood's Holl and the Elizabeth Islands, is a similar remnant of a vast moraine formed after the ice-front had withdrawn a short distance to the north. Indeed, the whole of Plymouth and Barnstable counties is "made land," as really as that of the Back Bay in Boston, only in the one case the earth was dumped, day by day, from the laborer's cart, and in the other year by year, from the melting front of the continental ice-sheet.

It is an instance of misleading poetic license which permits us to sing of the "rock-bound" shore upon which the Pilgrim Fathers landed, for there are no rock-bound shores in southeastern Massachusetts. The hills which first greeted the eyes of the Pilgrim Fathers are the irregular morainic accumulations so frequently characteristic of glacial margins. In this case the soil composing them consists of sand, gravel,

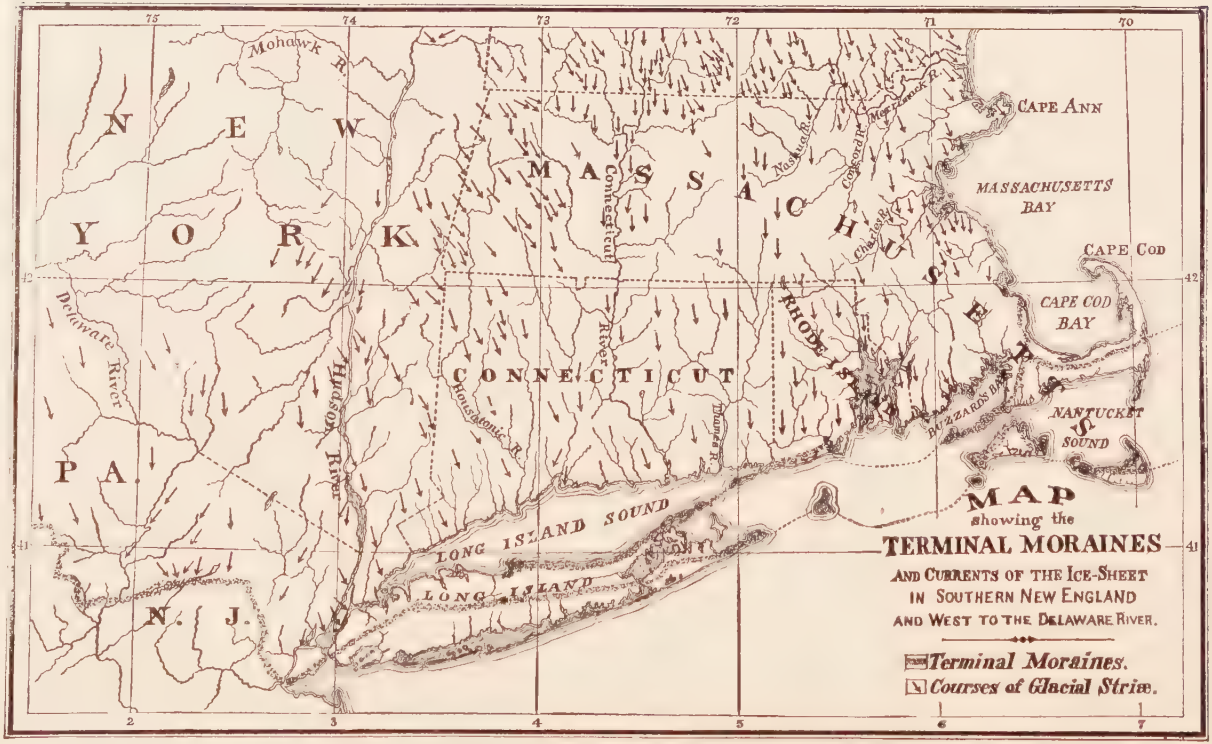

FIG. 44.- Notice that the easterly bearing of the striæ is greatest on the water parting between the Hudson and the Connecticut, and near the eastern shore. The larger valleys determined the direction of the lower strata of the ice.

and bowlders which have been scraped off by the ice from the mountains and ledges of New Hampshire and the intervening portions of Massachusetts, transported to the glacial margin, and there deposited in such quantities as to constitute the whole southeastern portion of the latter State. The three hundred and sixty lakes of Plymouth township are nothing else than a cluster of kettle-holes. Manomet Hill, southeast of Plymouth, is not a mountain which has been thrust up by convulsive agencies, nor yet a remnant of a partially eroded plateau, but a glacial deposit, hundreds of feet in height and many miles in extent. From the fact of its running nearly at right angles to the backbone of Cape Cod, Manomet Hill is spoken of by some as a medial moraine. But it is doubtful if it is necessary so to regard it. The retreat of a glacier, like the retreat of an army, is determined in part by the nature of the opposing foe. In the present instance there are abundant reasons for believing that the ice retreated by the left flank; for it is evident that the ocean had much to do in setting bounds to the general southeastern movement of the ice-sheet in New England. From the contour of the coast, it can be seen at a glance that the waters of the ocean had constant opportunity to eat in upon the ice from the east as well as from the south.

Nantucket marks the extreme southeastern limit. Here the ice maintained its position against opposing forces, until the outer line of moraines just mentioned was built up. The next line of defense taken up by the ice is that marked by the backbone of Cape Cod. The retreat had been farthest on the side most exposed to the ocean, and hence the distance between the moraine of Nantucket and that at South Brewster is much greater than the distance between Martha's Vineyard and Wood's Holl. The next line of defense taken up by the ice-front along the course of Manomet Hill, left Cape Cod and the whole shore of eastern Massachusetts open to the undisputed sway of the ocean.

The two lines of moraine so clearly marked in southeastern Massachusetts can be readily traced westward through

a considerable portion of Long Island. The exterior line, beginning at Montauk Point, forms the backbone of the island as far as Brooklyn, N. Y., the city itself being built upon it. The interior or parallel line, represented to the east by the backbone of Cape Cod and the Elizabeth Islands, disappears beneath the deeper waters of Buzzard's Bay, to emerge upon the mainland at Point Judith in Rhode Island, and give variety to the whole coast of the State westward from that point. This part of the moraine presents many features of special interest at Watch Hill, Fisher's and Plum Islands, and on the northern shore of Long Island as far as Port Jefferson. Westward from Port Jefferson only the external line of moraine hills is traceable, Staten Island in New York Harbor being a most interesting development of it. The northern and western portions of this island are covered with the peculiar combination of rounded knobs and circular depressions characteristic of moraines, while the southeastern portion of the island was just beyond the reach of the ice, and the deposits upon it are of an entirely different character.

Up to this point in our investigations some doubt may attach to the inferences concerning the limits of the great ice-sheet. For, since the ocean everywhere expands to the south, it may be asked, What certainty is there that its waters do not cover a belt of glacial deposits still farther out than those now visible? No positive answer can be made to this objection. But, on striking the coast of New Jersey opposite Staten Island, a fair field of investigation is at once offered, and doubt as to the substantial correctness of the delineation farther on need be no longer entertained. The line of moraine hills across New Jersey is a direct continuation of these forming the backbone of Long Island, and covering the northern half of Staten Island. Here they form a sharp line of demarkation between the glaciated region to the north and the unglaciated plains to the south. Beginning at Perth Amboy, the moraine bends northward through Raritan, Plainfield, Chatham, Morris, and Hanover,

FIG. 45.—The moraine according to Lewis and Wright. But the "Attenuated Border" extended below the mouth of the Lehigh. See Chapter VII, Continued.

to Rockaway, thence a little south of west to Belvidere on the Delaware, a few miles above Easton. The innumerable throngs of passengers between New York and Philadelphia can not, after their attention has been once called to the facts, fail to notice this moraine as the southward-bound trains pass through it, and emerge into a level, sandy region free from bowlders and all irregular drift deposits. At Metuchen and at Plainfield the transition is almost as clearly marked as that between land and water.

Before following the terminal belt farther west, where its characteristics are more or less disguised by the local topography, we will pause to consider more carefully some of the main characteristics of it as so far traced.

That these hills constitute a true moraine is evident from the fact that they are composed of loose material such as, both from the nature of the case and from observation, we know is actually deposited wherever the front of a glacier rests for any great length of time. A considerable portion of them consists of material which has been transported from various localities to the north, and deposited without any stratification. Some of the bowlders are unworn and angular, as if having been carried upon the back of the glacier. Others are partially rounded and scratched in such a manner as to show that they have been forced along through the mass of sand and gravel which everywhere underlay the moving field of ice. Sections, however, frequently show in these hills a limited amount of stratification. But this is not at all surprising, when we consider the manner of their formation; for the ice itself to a certain extent forms barriers to, and furnishes channels for the running water which its own melting provides, and so would itself afford the conditions necessary to a partial stratification of its own deposits.

The terminal moraine where best developed may almost be said to consist of innumerable ridges, knolls, and kettle-holes. The kettle-holes are of all sizes, and are situated in every imaginable position with reference to the general deposit; some of them, low down toward the base of the

moraine, are filled to the rim with water; others are but partially filled; while others are for the greater portion of the year completely dry. The angle at which the earth forming their sides stands is usually as sharp as the nature of the material will allow, and bowlders are as frequently found upon the inside of the rim as upon the outside.

The origin of kettle-holes has already been explained; but it is in place here to remark upon some of the general considerations supporting the theory already advanced.* It is evident, from an inspection of the depressions themselves, that they can not be the result of erosion, since the depressions are too irregular and too deep to have been formed by the plunging movement of water, and the material is too coarse for a water deposit. In some respects kettle-holes resemble what are called *sink-holes*, frequent in limestone regions, where a great amount of material below the surface is removed in solution, leaving numerous caverns whose roofs eventually sink in, and form the depressions characteristic of such regions. But kettle-holes abound in regions where no such caverns could have been formed, and are distributed over the country according to a method which could not have originated by the action of underground currents of water.

While the iceberg theory was in favor to account for the drift, it was not uncommon to hear these kettle-holes spoken of as places where icebergs had stranded, and in turning round and round had bored holes in the bottom of the ocean-bed over which they were floating; but, now that the iceberg theory is abandoned, and observations are more extended, the origin of kettle-holes is readily understood as an inevitable part of the glacial theory itself. Any one who will in the early spring-time take pains to observe the melting of masses of ice which have been covered by ashes and other refuse, or which have been partially buried beneath the *débris* of earth which some spring torrent has brought down from a neighboring hill, will find before him a very perfect

* See above, p. 66 *et seq.*

object-lesson as to the formation of kettle-holes. All the elements for their production are there, in and beneath the accumulated *débris*. As the heat slowly penetrates the protective covering, especially upon the sides, where it is the thinnest, it melts the ice and thus undermines the earthy material, which, in due time, slides down to the base, and thus gradually leaves a cone of ice in the middle, surrounded at the edges by a continuous ridge of dirt. Eventually the ice all melts away, and a miniature kettle-hole is formed. So far as I know, the application of this principle to the explanation of the extended phenomena under consideration was first made by the late Colonel Whittlesey,* of Ohio, in studying the Kettle range of Wisconsin. How completely this theory was confirmed by my study of the Muir Glacier, in the summer of 1886, has already been related.†

To prevent misapprehension, it should here be remarked that we have not intended to affirm that the whole bulk of Martha's Vineyard and Long Island consists of glacial deposits. The nuclei of those islands certainly existed before the Glacial period, for at Gay Head, on Martha's Vineyard, and in the vicinity of Port Jefferson, on Long Island, and at some other places, there are extensive beds of Tertiary clay underlying the glacial deposits, and rising above the water-level. The glacial deposits simply form a capping of more or less thickness to these older ones. It is still true, however, that the glacial deposits have determined, in the main, the present topographical features.

In following the moraine across New Jersey, we find that beginning at the sea-level, its base rises to a height of more than a thousand feet, where it crosses the Blue Hills of western New Jersey; and everywhere its surface is characterized by the knobs and kettle-holes, whose manner of formation has just been explained.

Crossing the Delaware River, these characteristic phe-

*Report upon "The Drift Formations of the Northwest," in "Smithsonian Contributions to Knowledge" 1866

†See above, p. 57 *et seq.*

[illegible] of the glacial deposits of Pennsylvania and adjoining portion of New York. Compiled by Wm. C. Alden, 1901. Arrows indicate direction of glacial strae. Scale, 1 inch=approximately 40 miles. (From United States Geological Survey).

nomena are developed in a marked degree upon the hills of Northampton county, Pa., running up to the base of the Kittatinny Mountain, some miles below the Delaware Water-Gap. West of the mountain, in Monroe county, the valley south of Stroudsburg is for several miles filled with the

FIG. 47.—A glaciated pebble, natural size, from the moraine on Pocono plateau, Pennsylvania, two thousand feet above the sea, Monroe county. The striæ along the longest diameter are well marked.

same characteristic ridges, knobs, and kettle-holes. On going still farther west, and rising suddenly fifteen hundred feet to the plateau of Pocono Mountain -the southern extension of

the Catskills—we find still the same characteristic deposits slightly modified by the different conditions. A range of hills, sweeping around this plateau for ten or twelve miles in a magnificent semicircle open toward the south, was discovered, in 1881, by Professor Lewis and myself to belong to the extreme and true terminal moraine of the continental ice-sheet. South of it one may go for miles upon a level, sandy plateau (about two thousand feet above tide) without encountering a bowlder or any foreign material; while the low range of hills, seventy-five or a hundred feet in height, is

FIG. 48.—The previous pebble viewed from the edge. The reversed side was free from glacial marks

literally formed of bowlders; among which may readily be recognized those of granitic origin, wrenched from ledges hundreds of miles to the north, and transported hither across the valley of the Mohawk or over the broad expanse of Lake

Ontario. Nicely ensconced within their wooded shores, there are here also the numerous lakelets so often found occupying kettle-holes, and forming the sources of streams which issue from the mountain-side to water the valleys below. There are few more interesting regions in which to study an ancient terminal moraine than the plateau of Pocono Mountain, between Tobyhanna and Tunkhannock townships, in Monroe county, Pa.

Passing still farther westward, and descending to the North Fork of the Susquehanna, twenty miles below Wilkesbarre, we find a remarkable terminal accumulation of glacial *débris* filling the valley to a great depth for some distance above Beach Haven. In the immediate vicinity of the river, which was one of the great lines of drainage during the Glacial epoch, the material is more or less modified by water-action; but the unmodified moraine can be clearly traced far up on either side of the valley. A few miles to the westward, on the other side of Huntingdon Mountain, and but ten or twelve miles south of the southern wall of the Alleghanies, the line of terminal deposits can be traced past Asbury, through a whole township and some miles beyond, up the eastern side of Fishing Creek. Through all this distance, on the east side of the creek, there is nothing upon the surface but these irregular and confused features of a well-marked terminal deposit; while on the west side of the creek, not a sign of glacial action can be seen. But suddenly, above the town of Benton, the belt of confused deposits of stone and gravel begins to descend the eastern side, and after crossing the valley diagonally, rises, like a broken-down Chinese wall, upon the western side.

It is important to make a cautionary remark at this point. The boundary so far in eastern Pennsylvania as here delineated is that which was determined by Professor Lewis and myself in 1881, but it became probable that there was a small margin of error in our delineation; while from Luzerne county on, the varied fortunes of the terminal moraine are difficult of description. The north-cen-

tral counties of Pennsylvania are covered with forests, and are cut up into gorges extremely difficult of access. Nevertheless, in Lycoming county, upon a plateau at Rose Valley, three or four miles to the east of Lycoming Creek, and several hundred feet above it, large kettle-holes with their surrounding ridges of gravel, and their accompanying bowlders and striated rock-surfaces, are marked features of the landscape at a height of 2,000 feet above the sea; while upon the west side of the creek these features are totally absent for some miles above. Similar developments are met, at occasional intervals, all along the line of the great continental divide in Potter county, whence the waters flow to the widely separated regions of the Gulf of St. Lawrence, Chesapeake Bay, and the Gulf of Mexico. The same pronounced features already described mark the terminus of the great ice-sheet where it crossed the valley of the various tributaries entering the Alleghany River from the north, in Cattaraugus county, N. Y. In that State these are specially noticeable at Ellicottville, at Little Valley, and upon the high lands upon either side of the Eastern Branch of Conewango Creek near Randolph. As the glacial margin swings back again to the Pennsylvania line, it is marked by numerous and impressive accumulations in Warren county, one of the most accessible and notable localities being where it crosses the valley of Conewango Creek at Ackley, a few miles above its junction with the Alleghany River at Warren. Here the marginal line of glacial deposits may be clearly seen as it descends from the highlands on the east diagonally to the valley, filling it to a great depth, and rising over the hills in its onward course to the southwest. At this point in the valley, as at some other places which could be mentioned, the northern side of the moraine is more abrupt than the southern.

It was here that we made some of our first and most exact discoveries as to the limit of the ice west of the Alleghanies. Professor Lewis and myself, who were pursuing the investigations together, had already learned the charac-

teristics of the great lines of glacial drainage extending to the south of the glacial limit, and of which more particular mention will be made in a future chapter; but it was here that we first detected the exact relation of these lines of glacial drainage to the great ice-movement. Coming up from Warren toward the glacial boundary, the valley of the Conewango is seen to be filled increasingly full of gravel deposits arranged in terraces on either side of the small stream. The height of these above the stream is sixty or seventy feet. At first the gravel is rather fine, but is constituted largely of water-worn granitic fragments, which could have come within range of the stream only by glacial transportation from the far north. On proceeding a few miles farther north, these terrace deposits become more and more irregular, being thrown up into great ridges, and at the same time the material becomes less water-worn and much coarser. Below this point we had searched diligently in the gravel for scratched stones, but none were anywhere to be found. A mile or two from Ackley, however, we began to find pebbles upon which the glacial scratches could be dimly traced. They had been partially water-worn, but had not been rolled far enough to completely obliterate their glacial marks. Upon reaching Ackley, we found the whole valley occupied by a true glacial deposit, terminating abruptly to the north, and through which the stream had cut a narrow channel. The moraine ridge, or dam, as we might call it, rises from 100 to 150 feet above the present bed of the stream, and is equally well developed upon both sides. Scratched stones and granitic fragments abound, and it is well marked upon either side of the creek by the characteristic kettle-holes. Above Ackley, for many miles, the Conewango pursues a sluggish course, and is bordered by extensive marshy land. The explanation of all this is that the ice-front remained for a somewhat protracted period at Ackley, allowing the large accumulations immediately below to take place. But its retreat from Ackley for many miles northward was too rapid to permit of any marked terminal accumulations:

CHAPTER VII.

(CONTINUED.)

THE ATTENUATED BORDER.

So far it has been thought best to adhere closely to the delineation of the glacial margin through New Jersey and Pennsylvania as given in the report of Lewis and Wright in Vol. Z of the Pennsylvania Survey. But in the preparation of that report we were laboring under the false impression that the extreme glacial margin was always marked by a distinct moraine. This error was partially recognized by us in speaking as Professor Lewis, especially, did, of a bordering "fringe" of sporadic glacial deposits extending some distance farther south than the line as marked on our map. The study of this was taken up later by Professor Edward H. Williams and carried on across the state with the result that the boundary of the "fringe" or "attenuated border" was found to extend on an average, about twenty miles farther south than our "terminal moraine." Similar results were found to prevail in New Jersey by Professor Salisbury, Professor A. A. Wright, and myself.

To be specific: The extreme glacial limit in New Jersey reached to an irregular line running from Bound Brook, a little south of Plainfield, to Riegelsville, on the Delaware, a few miles south of Easton, Pa. So far, land-ice evidently extended at one time. The striated bowlders found by Professor Salisbury and others still farther south were doubtless carried by floating ice when the land was depressed to the extent of about 200 feet, of which evidence will be given in a later chapter.

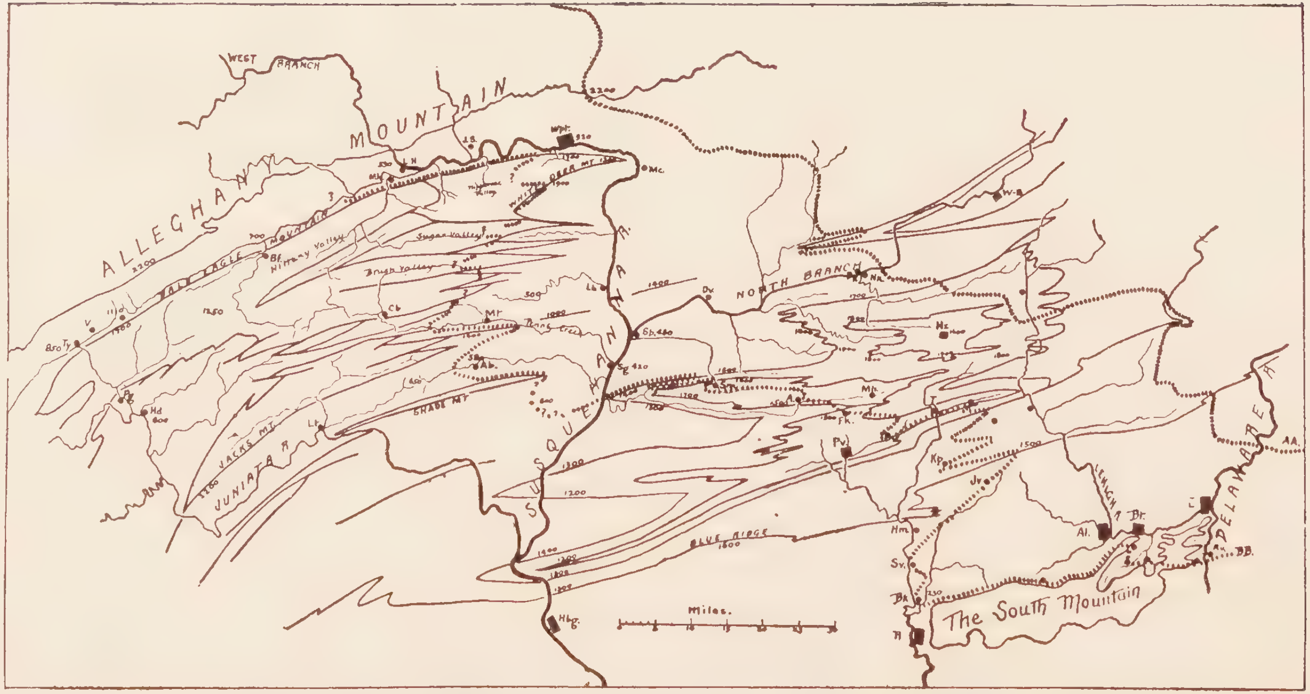

FIG. 49—*AA*. Moraine of Lewis and Wright; *BB*. Southern ice limit; *A*. Ashland; *Ab*. Adamsburg; *Al*. Allentown; *Bf*. Bellefonte; *Bk*. Berwick; *Bl*. Berkeley; *Bt*. Bethlehem; *Co*. Coburn; *Dv*. Danville; *E*. Easton; *Hbg*. Harrisburg; *Hd*. Huntingdon; *Hm*. Hamburg; *Hz*. Hazelton; *Jv*. Jacksonville; *Kp*. Kepner; *Lb*. Lewisburg; *Lt*. Lewistown; *L. H*. Lock Haven; *Mc*. Muncy; *M. H* Mahanoy City; *Mh*. Mill Hall; *Nk*. Nescopeck; *Pg*. Petersburg; *Pv*. Pottsville; *R*. Reading; ***Rv*. Riegelsville**; *Sb*. Sunbury; *Sg*. Selinsgrove; *Sm*. Shamokin; *Sv*. Shoemakersville; *T*. Tamaqua; *V*. Vail; *W. B*. Wilkes-Barre; ***Wpt*. Williamsport.** *Map by Williams*.

In Pennsylvania it is interesting to note that the Alpine plant Sedum Rhodiola, long known to exist in the narrows of the Delaware River south of Riegelsville, marks the boundary of the attenuated border in the extreme east. Thence the line skirts the Triassic areas on the south side of the Durham Valley, just south of Bethlehem, turns westward to the Schuylkill at Berkeley a few miles north of Reading; thence northward on the east side of the Schuylkill River to Shoemakersville and going over the Blue Ridge Mountain in a zigzag line, passes through Jacksonville and Kepner to Tamaqua where it crosses the Schuylkill. Thence running westward it crosses the Little Schuylkill at Wetherill Junction four miles from Pottsville depot, thence westward through Ashland and Shamokin to the Susquehanna River a few miles south of Selin's Grove. West of Pennsylvania this attenuated border assumed greater and greater proportions, attaining its largest extent in northeastern Kansas, from which fact the deposits have been denominated "Kansan Drift." From the thinness of the "Kansan" deposits and their more highly oxidized condition, this drift has been assumed to be vastly older than the deposits marked by the terminal moraine of Lewis and Wright and, unfortunately, have given name to the whole attenuated border and in popular apprehension carried with it the assumption that they are all synchronous in age. With this protest, however, it will be best to continue the use of the term and speak of these deposits as "Kansan" and of the latest ones as "Wisconsin."

One of the most impressive facts ascertained by Professor Williams concerning this earliest advance of the ice over the region between the Lehigh and the Susquehanna valleys was that of the formation of an ice-dam across the mouth of the Lehigh at Easton, producing a temporary lake (which might properly be named Lake Williams) extending from Allentown to Topton and there overflowing into the Schuylkill at Berkeley a few miles above Reading. The depth of water

in this lake was 280 feet at Allentown and its outlet at Topton was 500 feet above tide. The shore lines can easily be traced along the whole distance. The overflow into the Schuylkill carried floating ice and glacial *débris* into that river so that considerable deposits of glacial material were made in some places, notably at Norristown only a short distance above Philadelphia. Much of the gravel in West Philadelphia is believed by Professor Williams to have come down the Schuylkill through this channel, and through the Little Schuylkill, as all the coal region drained by the latter was covered by ice.

The efficiency and comparative recency of the glacial action over this "Kansan" area in Pennsylvania is well shown at Morea, a few miles north of Pottsville, and only one mile north of the extreme limit of glaciation at this point. Here, for commercial purposes, the "Mammoth bed" of anthracite coal has been stripped of its covering of "Kansan till." The coal vein here outcrops in nearly vertical planes favoring the percolation of water and the disintegration of the surface. Beginning at the top the covering consisted of from six to ten feet of sandy till with occasional bowlders five feet in diameter; below this were eighteen inches of crushed anthracite entirely fit for the market; then came three-fourths of an inch of rotten coal mixed with angular specs of slate; then one inch of sandy clay with rolled and angular quartzite and slate pebbles; then one-half inch of fine bright crushed coal; and below this the glaciated surface, shown in the illustration, the upper three-fourths of an inch of which was so soft and fully rotted that it could be scratched with the finger nail. Below this was an indefinite extent of solid bright marketable coal. The recency of the glaciation appears in the fact that south of the glacial border, only one mile away, the coal is so disintegrated as to be worthless for many feet below the outcrop. At the same time the covering in the glaciated area is so sandy and porous as to be very little protection to the surface of the coal.

Plate VI—North outcrop of Mammoth Bed overlaid by Kansan till, Morea, Pa. (Photo by Williams.)

Another noticeable characteristic of deposits over this attenuated border is that the prevailing, highly oxidized material is mingled with a considerable amount of fresh unoxidized material brought from farther north, showing that the oxidization was mainly preglacial, and that the age of the deposit must be reckoned from the accession of the fresh material. In the effort to determine the age of these deposits from the extent of the oxidization, it also should be ever kept in mind that the ice moved first over an area whose surface had been deeply disintegrated and oxidized during the long ages of tertiary time. It was the product of this disintegration which was first incorporated into the mass which was moved along by the ice, and this naturally was carried farthest. The contributions made later were such fresher portions of the rocky surface as had been below the action of the disintegrating agencies of the Tertiary period and so would be mingled with the earlier material wherever the ice overrode the deposits of the primary advance.

West of the Susquehanna the ice pushed over the plexus of mountains south of Williamsport, rising to a height of 1,200 feet above the river and ending along a zigzag line bearing northwestward, as shown in the map, reaching the west branch of the river at Lock Haven. In this area several most interesting and even startling results were produced. Though the ice did not reach the valley of the Juniata River, Professor I. C. White had reported at various places along the border of the river, especially at Huntingdon "great heaps of bowlder trash, both rounded and angular . . . . and these often very much resemble genuine drift heaps." Sometimes these reach an elevation of 100 feet above the river. Later, Professor Williams found unmistakable glaciated stones in the corresponding high level terrace at Lewistown; while on the western side of Warrior's Ridge a little above Huntingdon, where the Juniata cut a narrow gorge through the mountains there was a small deposit of erratics between 300 and 400 feet above the river.

All these facts became clear when it was known that the ice crossed the Susquehanna and advanced to the summit of the mountains lying between that river and the Juniata. The glacial gravels at Lewistown came from a stream which poured over the col at Adamsburg where the ice was arrested in its movement. The bowldery deposits farther up the Juniata near Huntingdon came from an immense glacial stream which poured over the col between the head of Bald Eagle Creek and a branch of the Juniata joining the main stream at Tyrone. Bald Eagle Valley had been occupied by a long narrow glacial lake occasioned by the obstruction of its mouth at Lock Haven, where the depth of the water was 570 feet. The col above Tyrone has an elevation of 1,100 feet. The shore lines of this temporary lake (which has appropriately been named Lake Lesley) can easily be traced, and is marked by great cones of gravel where tributary streams came in from the east. The erratics thrown up to such a great height on the west side of Warrior's Mountain are evidently due to high and tumultuous water produced by an ice-gorge where the stream enters the narrow channel across the mountain ridge. Numerous evidences of the damming of the West Branch of the Susquehanna are to be found as far up as Emporium on the Sinnemahoning River.

Northwestward from Lock Haven the border of the Kansan drift is lost in the wildernesses of Lycoming and Potter counties, becoming recognizable again near Coudersport, beyond which it disappears under the moraine of Lewis and Wright to reappear again on the highlands of Warren, Venango and Butler counties west of the Allegheny River where the elevations rise above the flooded regions produced by the ice-dams which reversed the drainage of the whole basin west of the Alleghenies. A simple illustration shows the probable overlapping of borders as suggested by Professor Williams.

The history of the reversal of the drainage of the Alle-

Fig. 50—Lake Lesley. *E.* Emporium. *H.* Harrisburg. *Sb.* Sunbury. *Wp.* Williamsport. *Ty.* Tyrone.

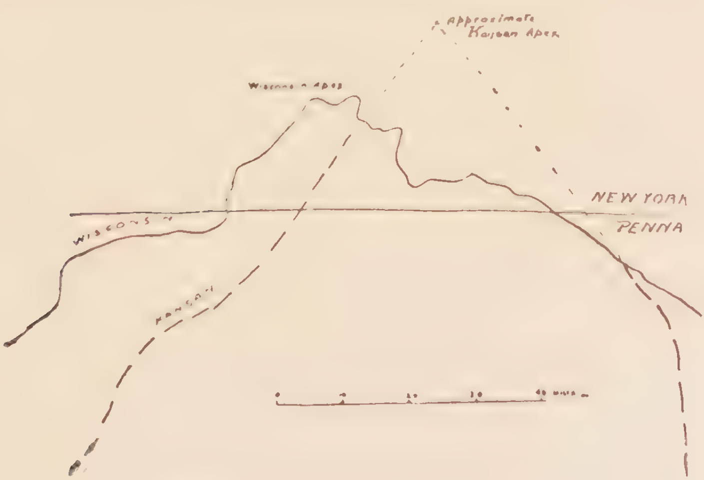

Fig. 51—Advance of Wisconsin Ice over the Kansan Border near the apex of New York.

gheny might seem to be more appropriate to the chapter on Glacial Dams, Lakes, and Waterfalls, but it is so intimately related to the facts connected with the extreme extension of the continental glacier in the Appalachian region that we introduce it here, expecting the reader to refer to it again for facts which have an important bearing on later theoretical discussions. In itself, however, it is one of the most interesting problems ever presented to the geographer and the geologist: I am permitted to quote freely from the unpublished report of Professor E. H. Williams upon the subject, and to make use of his extensive collection of facts.

LAKE ALLEGHENY.

Professor Williams writes, "'Kansan' drift throughout Pennsylvania is characterized by native copper. I have a piece from Warren (40 feet below the surface), and farmers have come to me at Bethlehem to come and see their 'copper mine.' Mr. Albert G. Rau, Dean of the Moravian College has, at numerous points, picked up rolled fragments from 'Kansan' gravels. This seems to point to a Lake Superior passage by the ice—hence the glacier which first invaded this part of the state came from the northwest, and therefore moved against the drainage and presented so effectual a dam that, with the exception of the hilltops, northwestern Pennsylvania and adjacent New York were submerged by a lake whose eastern shores in Pennsylvania were the highlands of Potter County and their extension southward, while McKean County extended into it like a broad promontory deeply gashed by its river systems. The name *Allegheny* is proposed for this lake which originated long before the advent of glacial ice to the immediate region and which, being but slightly drained subglacially, sent its waters southwards over the cols into other drainage systems. As the glacier advanced it constricted the area of escape and when it reached the line of the present Allegheny it formed,

with the eastern highlands a trough through which the torrents cut their way southward. The presence of high water sediment at Franklin shows that the col which imposed the height to the lake was south of that place, and also shows that all intervening cols were submerged and the drainage systems

Fig. 52—Lake Allegheny. *B.* Barnesville. *C.* Clarendon. *F.* Franklin. *I.* Irvine. *O.* Oil City. *T.* Thompsons. *W.* Warren.

between them aggraded. When the most distant and restraining col became degraded so that the interior ones came within the area of scour they were cut down gradually and readily, as the porous and loosely cemented sandstones rapidly yield to water carrying only its own sands, and the shales carry

strata so highly jointed that they collapse under a slight impact, and undermine the overlying and more resistant strata. The result was an aggradation of older systems to the level of the older cols and the present alternations of the old aggraded valleys with low angles of slope and gorges varying from a steep V-shape to one with nearly vertical walls extending far below the present water level and attesting to the torrential flows which degraded them."

In estimating the significance of these facts, however, it is important to bear in mind the extensive changes of land levels which took place before, during, and after the Glacial period. (1) It will be shown in a later chapter that there was extensive elevation of the glaciated region in Tertiary times increasing in extent towards the north. In all probability this amounted to more than 2,000 feet in the central part of the glaciated area. This, in itself, may have had something to do in reversing the drainage of many northerly flowing streams.

(2) But at the close of the Glacial period the northerly areas of the glaciated region were depressed so that they stood at Montreal 600 feet lower than the present level, and farther north still lower. It is impossible to tell how far south this glacial depression extended in the northern part of the United States.

(3) Since the retreat of the ice there has been a differential re-elevation of the glaciated area increasing towards the north, and amounting to 600 feet at Montreal and 1,000 feet farther north. The axis about which this differential re-elevation revolves seems to run east and west through Central New York and the basin of Lake Erie. In estimating, therefore, the height of the col, in the lower Allegheny or middle Ohio Valley, which determined the level of Lake Allegheny we must not forget that this differential northerly depression during glacial times may make the water levels in the upper part of the lake appear to be higher than they

absolutely were. But we will give the facts as they now appear.

The facts will be best appreciated by somewhat detailed study of the portion of the Allegheny Valley which passes through Warren and McKean counties in Pennsylvania and Cataraugus County in New York. The upper Allegheny descends from the high tableland of Potter and McKean counties in a northerly direction, and consequently was obstructed by the advancing ice, both of the Kansan and of the Wisconsin epochs. Abundant evidence of the slack water thus produced is seen all along this part of the valley, from Coudersport and Keating through Port Allegheny and Turtle Point down to Salamanca in New York where the stream turns abruptly to the south. But the evidences of a flooded condition of the valley at the time of the extreme extension of the ice still continues down stream well-nigh to the Ohio River. Everywhere along the course of this valley fans of gravel appear at the level of the glacial high water, wherever tributary streams come in from a higher level. At Warren this fan is 400 feet above the present water level and at Franklin, 650 feet.

In the words of Professor Williams' report, "The affluents of the Allegheny show traces of high water. Those flowing from the glacier are generally aggraded and reversed: those from the Pennsylvania highlands are also aggraded but with local material. The narrowness of their valleys allowed the removement of sediment when the water level brought the bottoms within the area of scour, and it is only in favored places that the evidences remain. Some, however, as Red Bank Creek, and the Kiskiminetas-Conemaugh system show abundant traces of deep sedimentation. . . . At times the conjunction of sudden bends in the main stream and the debouchment of short side valleys which branch from the same area have caused eddies or deflections of the main stream and have aggraded the side valleys so as to resemble portions of a river channel at elevations higher than the present one."

The most interesting collection of facts appears in the vicinity of Warren at the junction of Conewango Creek and the Allegheny River. With little doubt the preglacial drainage flowed from some distance south of Barnesville northward through Clarendon and Warren into the Conewango and thence on into the Lake Erie basin, and at a level considerably lower than that of the present river.

The rock trough of the Conewango is much wider than that of the Allegheny for several miles up the stream, showing that the preglacial drainage was through the Conewango. This greater breadth continues down the Allegheny to Irvine, and thence up the Brokenstraw to the glacial limit. Below Irvine the trough of the Allegheny again becomes constricted throughout almost its entire course. Usually its lower rocky trough below this point is not more than three-fourths as wide as it is above Irvine, and at one point near Parker its width is less than half that in the upper part of the valley.

But the broad preglacial trough of the Conewango extends across the Allegheny through Stoneham and Clarendon to Barnesville. The gravel deposits here are of the most interesting and significant character. East of Warren upon a rock shelf 250 feet above the present stream there is an extensive gravel deposit from twenty to fifty feet in thickness, containing many Canadian pebbles, and continuous with and forming a part of undisturbed gravel strata extending down the side of the trough to the river level. It is noteworthy also that the lower part of this deposit for a considerable depth is fine sand, and at the bottom blue clay, indicating deposition in still water. Crossing the Allegheny to Stoneham we find here also a gravel deposit overlying deposits of fine sand and blue clay containing frequent logs of trees such as now cover the hills, and extending to a depth of 160 feet below the surface in the middle of the trough. South of this is a cranberry swamp two or three miles in length extending to Tiona, where we again meet a gravel deposit filling a

buried valley as deep as that underlying the swamp and the gravel at Stoneham. But while the Stoneham deposit contains Canadian material, that from Tiona to Sheffield consists wholly of local material which has been brought down from the sides of the mountain to the east and south.

Here again an interesting thing occurs. The gravel deposit between Sheffield and Barnesville rises to the level of a col which leads through a precipitous gorge into and down the Tionesta River reaching the Allegheny at the town of the same name. But the northern branch of the present Tionesta rises a considerable distance west of Stoneham; the deposit at Stoneham being the watershed between that place and the Upper Allegheny only a few miles to the north. From Clarendon to Barnesville this branch flows over a preglacial trough nearly 200 feet in depth, then the present stream occupies for the rest of its course a narrow rocky trough bordered only in a slight degree with gravel deposits.

The explanation of this, as already intimated, is that upon the obstruction of the northerly flowing preglacial stream through the Conewango Valley, deep slack water was produced in the Upper Allegheny Valley, the depth being regulated by the height of the highest col at the south. The depth of the water at Clarendon and Warren was about 500 feet, as shown by the depth of the buried rock bottom of the river at Warren added to the height of the gravel terraces in the vicinity of Clarendon. In such depth of water, held in check by an obstructing col somewhere at the south the lower portions were stagnant so that blue clay and fine quicksand would settle and this is what is found to a thickness of about 200 feet. Above this approximate level coarse sand and gravel, with occasional large pebbles, was spread in dumps and fans wherever tributary streams brought in material, which was pre-eminently the case where streams entered from the glaciated region. Such are the terraces of glacial gravel already described just east of Warren, and a still larger and

higher one a mile, or so, above the mouth of the Conewango in the narrower valley of the Allegheny.

A still more interesting and significant dump lies about one-half mile west from Clarendon where there is an extensive gravel deposit running parallel to the valley and resting on the older local slopes. The surface of this deposit is 160 feet above the present level of the valley. Its depth, however, as shown by numerous driven wells is 308 feet, of which the upper sixty feet is gravel containing a noticeable amount of granitic material, underlaid by 148 feet of sand with a small amount of gravel, and this in turn by 100 feet of clean clay. In this clay the drill, in some cases, went through a stratum of logs.

Anticipating, somewhat, the more comprehensive discussions of the chapters on Preglacial and Glacial Drainage, the order of events as indicated by the facts in this interesting locality will be found to be as follows:

In early and middle Tertiary times the drainage of the Allegheny and upper Ohio basins was northward while the land levels were lower in the north than they were in the south. During the later part of the Tertiary period an elevation of land went on over all the region afterwards covered with glacial ice, being greater in the north than in the south. This differential elevation perhaps had much to do with the reversal of the drainage lines of which we have such abundant evidence. But the advance of the glacial ice front against the northerly lines of drainage completed the reversal, so that unprecedented floods of water poured over the cols between the reversed channels, wearing them down with great rapidity as is shown by the narrowness of the troughs and steepness of the sides of the gorges through various sections of the present drainage lines. The position of the highest col was probably a considerable distance below the upper end of the Ohio River not unlikely a short distance below Wheeling, W. Va., as suggested by Chamberlin.

In this view, the rock erosion of the Allegheny and Ohio

valleys is mainly preglacial, and the high level gravel terraces which line the troughs through their entire extent were deposited during the various stages of this rock erosion. The

FIG. 53.—Map of Upper Allegheny Valley, Pa.

difficulty of accepting this hypothesis, arising from the fact that it involved believing that the deposition of the high level terraces went on without the filling of the lower and

narrower portions of the rock gorges through which the stream runs, was met by the sagacity of Professor E. H. Williams, whose intimate knowledge of the subject obtained as a hydraulic and mining engineer has enabled him to make the whole process clear. This is checked by the fact that the planes of sedimentation uniformly follow the contours of the underlying rocks and show that, first, those contours were carved out before the deposition began and, second, that the later sediments poured over them as in the case of ordinary bars and fans and varied from coarse to fine with the velocity of the current.

As tidal currents scour out and keep clear certain channels where their action is concentrated, so a powerful river torrent scours out its main channel to a great depth, while it throws up and deposits its sediment both coarse and fine upon the higher bordering levels whenever there is a bend in the trough changing the course of the current, or wherever there is a strong tributary coming in at a broad angle. The forces involved are nothing other than those which form an ordinary flood plain, except that they are extremely vigorous. On following down the Allegheny and Ohio valleys all the high level gravel terraces can be accounted for by the action of the tumultuous torrents from the melting ice of the closing stages of the Glacial period as they poured through the tortuous channel as it now exists.

[illegible] Warren, showing bar on top of slack water sands

FIG. 55—Bar at Warren, showing bedding and elevation above Warren.

CHAPTER VII.

(CONCLUDED)

THE GLACIAL BOUNDARY WEST OF PENNSYLVANIA.

Through Columbiana county, Ohio, as in the adjoining counties of Pennsylvania, there is, to the south of the heavy accumulations of till, a fringe of thinner glacial deposits from one to three miles wide. Over this margin there are scattered evidences of glacial action, consisting of granitic bowlders and patches of till here and there upon the highlands,

* See G. F. Wright, "The Glacial Boundary in Ohio, Indiana, and Kentucky," Western Reserve Historical Society; also "Ohio Geological Report," vol. v, pp. 750–771; T. C. Chamberlin, "Extent, etc., of the Wisconsin Kettle Range" ("Transactions of the Wisconsin Academy of Sciences," vol. iv); "Geological Survey of Wisconsin," vols. ii and iii (Madison, 1877–'80); "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch" (United States Report); George H. Cook, "Annual Reports for New Jersey for 1877, 1878"; G. M. Dawson, "On the Superficial Geology of British Columbia" ("Quarterly Journal of the Geological Society, 1878," vol. xxxv, p. 89); J. W. Dawson, "Changes of the Coast-Level in British Columbia" ("Canadian Naturalist," April, 1877); G. K. Gilbert, "On Certain Glacial and Post-Glacial Phenomena of the Maumee Valley, Ohio" ("American Journal of Science, 1871," vol. ci, p. 339); C. H. Hitchcock, "Moraines of North America" ("Popular Science Monthly," 1881); Clarence King, "United States Geological Explorations of the Fortieth Parallel," vol i; "Systematic Geology" (Washington, 1878); Lewis and Wright, "Report on the Terminal Moraine in Pennsylvania and Western New York, Second Geological Survey of Pennsylvania, Z"; Warren Upham, "The Northern Part of the Connecticut Valley in the Champlain and Terrace Periods" ("American Journal of Science, 1877," vol. cxiv, p. 459); "The Formation of Cape Cod" ("American Naturalist, 1879," vol. xiii, pp. 489, 552); "Geological Survey of New Hampshire," vol. iii (1878); "Geological and Natural History Survey of Minnesota" (Report for 1879); "Terminal Moraines of the North American Ice-Sheet" ("American Journal of Science, 1879," vol. cxviii, pp. 81, 197); Charles Whittlesey, "Fresh-Water Drift of the Northwestern States" ("Smithsonian Contributions, 1866," vol. xv); N. H. Winchell, "The Drift Deposits of the Northwest" ("Popular Science Monthly," vol. iii, pp. 202, 286); "Geology of Minnesota" (Annual Reports, 1872, etc.).

*See also full lists given in the Appendix.

at an elevation of from 300 to 500 feet above the Ohio River. North of this fringe the till is continuous, and everywhere of great depth. At Palestine, on the eastern edge of the county, and at New Alexandria, near the western side,

FIG. 56.—Map of the glaciated region of Ohio, showing a part of its extension in Kentucky.

wells are reported in the till fifty feet deep. This is upon the highest land in that part of the country, and the glacial deposits are marked, in a moderate degree, by the knobs and kettle holes characteristic of the moraine upon the south shore of New England. A mile or two west of Canton, in Stark

county, the accumulations of glaciated material are upon a scale equal to anything upon Cape Cod. The northern part of Holmes county is covered with till, which is everywhere of great depth, and in numerous places near the margin displays, though in a moderate degree, the familiar inequalities of the New England moraine. After the southern deflection in Knox county, the glaciated region is entered near Danville, from the east, on the Columbus, Mount Vernon, and Akron Railroad, through a cut in till a quarter of a mile long, and from thirty to forty feet in depth. At the old village of Danville, near by, upon a neighboring hill, wells are reported as descending more than a hundred feet before reaching the bottom of the till. Through Licking county, both north and south of Newark, the depth of the glacial envelope is great up to a short distance of its eastern edge. At the old canal reservoir, in Perry county, the characteristic features of a moraine come clearly out. The hill just to the south of this, on which Thornville is built, is a glacial deposit in which wells descend from thirty to fifty feet without striking rock. This is upon the highest land in the vicinity. The reservoir itself seems to be simply a great kettle-hole. All through Fairfield county the glacial accumulation is of a great depth down to within a very short distance of its margin.

But perhaps the most remarkable of all the portions of this line in Ohio is that running from Adelphi, in the northeast corner of Ross county, to the Scioto River. The accumulation at Adelphi rises more than two hundred feet above Salt Creek, and continues a marked feature in the landscape for many miles westward. Riding along on its uneven summit, one finds the surface strewn with granitic bowlders, and sees stretching off to the northwest the magnificent and fertile plains of Pickaway county, while close to the south of him, yet separated by a distinct interval, are the cliffs of Waverly sandstone, rising two hundred or three hundred feet higher, which here and onward to the south pretty closely approach the boundary of the glaciated region.

Through the southeastern corner of Highland county, and the northwestern corner of Adams, the terminal accumulations are less marked than in Ross county: still, their boundary can be accurately and easily determined. It approaches the Ohio River, in the vicinity of Ripley and Higginsport in Brown county, and crosses it from Clermont county, entering Kentucky half a mile north of the line between Campbell and Pendleton counties in that State. Cincinnati was covered with ice during a portion of the period. There are undoubted glacial deposits within the bounds of the city at the railroad station at Walnut Hills, and near Avondale, at a height of about four hundred feet above the river. At North Bend, twenty miles below Cincinnati, the tunnel of the railroad leading from the Ohio to the Great Miami River is through an indubitable glacial accumulation which rises two hundred feet above the river. The northwestern part of Boone county, Ky., was also covered with the ice to a distance of several miles south of the Ohio River.

Through Indiana the glacial boundary, after following the Ohio River to within ten or twelve miles of Louisville, Ky., suddenly bends to the north, leaving a large triangular portion of the State unglaciated. The base of this unglaciated triangle extends from Louisville to the Illinois line, and its apex is about thirty miles south of Indianapolis. The exact course of this part of the boundary is along a line running from the neighborhood of Louisville northward through Clark, Scott, Jackson, Bartholomew, and Brown counties to Martinsville in Morgan county, where it again turns west and south nearly parallel with, and west of, the West Fork of White River, through Owen, Greene, Knox, Gibson, and Posey counties, crossing the Wabash River into Illinois, near New Harmony, the seat of Owen's celebrated socialistic experiment.

In Illinois the line continues in a southwesterly direction through White, Gallatin, Saline, and Williamson counties, where it reaches its most southern limit near the northern boundary of Johnson county, fifty or sixty miles north of

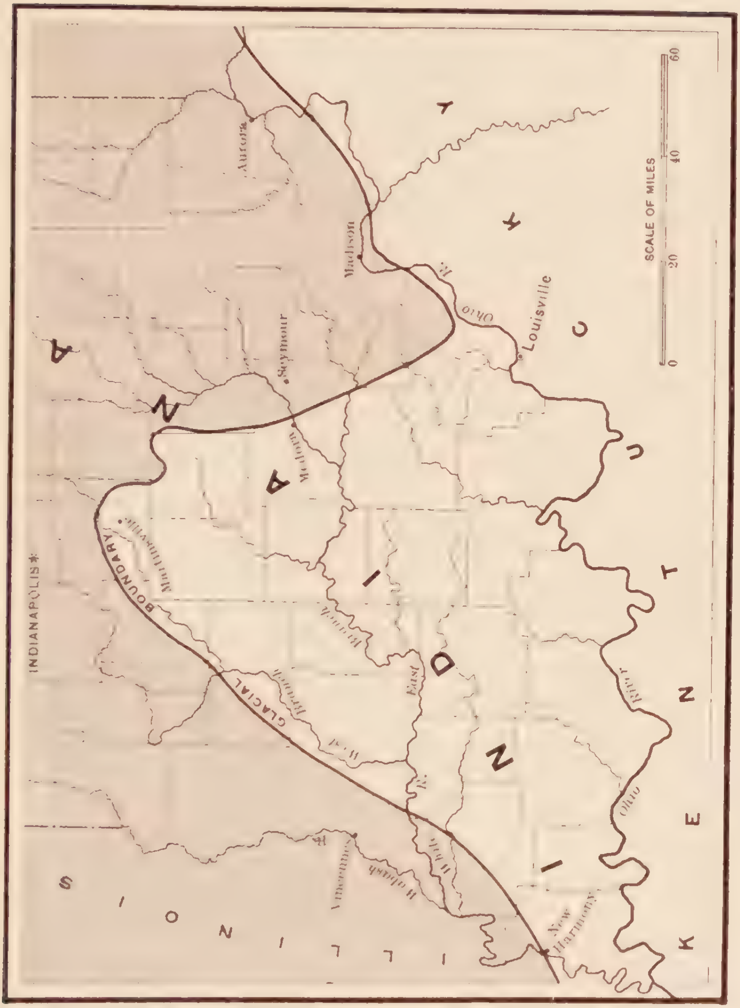

Fig. 57.—Glaciated region of southern Indiana.

Cairo, a little below latitude 38°. From Williamson county it starts westward upon its final course to the north, reaching the Mississippi River, near Grand Tower, in Jackson county. From this point to the vicinity of St. Louis the Mississippi runs nearly southeast, so that the glacial boundary in its

northwest course is coincident with the bluffs on the northeast side of the river through Jackson, Randolph, and Monroe counties, Ill.

So far I have traced the southern boundary myself, and the information here given is nearly all at first hand. Beyond the Mississippi competent members of the United States Geological Survey have traced the course approximately to the Pacific Ocean. From these data we know that across the State of Missouri the Missouri River approximates closely to the glacial limit. The line enters Kansas a little south of Kansas City, and runs nearly west for a hundred miles to the vicinity of Topeka, where it curves northward, crossing the State of Nebraska about one hundred miles west of the Missouri River, and reaching the southern line of Dakota, near the junction of the Niobrara and the Missouri. In eastern Kansas and Nebraska the exact limits of the glaciated area appear, from the reports, to be somewhat difficult of determination. It would seem that the action of water and floating ice was predominant in determining the character of the glacial deposits over that region, and the theory is plausibly suggested by Professor Todd that the extension of the ice beyond the Missouri formed glacial dams across the valleys of the Kansas and Platte Rivers, so as to maintain for a short period temporary lakes of a considerable extent, which received and distributed the bowlder-laden fragments of ice, as well as the finer elements of the glacial deposits. The most of the glaciated portion of these States is deeply covered with fine loam, or *loess*, which is probably a water deposit, and, as we shall hereafter see, is on good grounds believed by Chamberlin and Salisbury to be an "assorted variety of glacial silt directly derived from glacial waters." *

Through Dakota the glaciated region is bounded by a line which runs northward from near the junction of the Niobrara

* "Preliminary Paper on the Driftless Area of the Upper Mississippi Valley," by Thomas C. Chamberlin and Rollin D. Salisbury, in the "Sixth Annual Report of the United States Geological Survey," p. 304.

and Missouri Rivers, and keeps pretty close to the west edge of the river trough as far up as the mouth of the White River. Beyond this it breaks over the western edge of the trough for a short distance, and keeps approximately parallel with the river, from five to ten miles west of it, until reach-

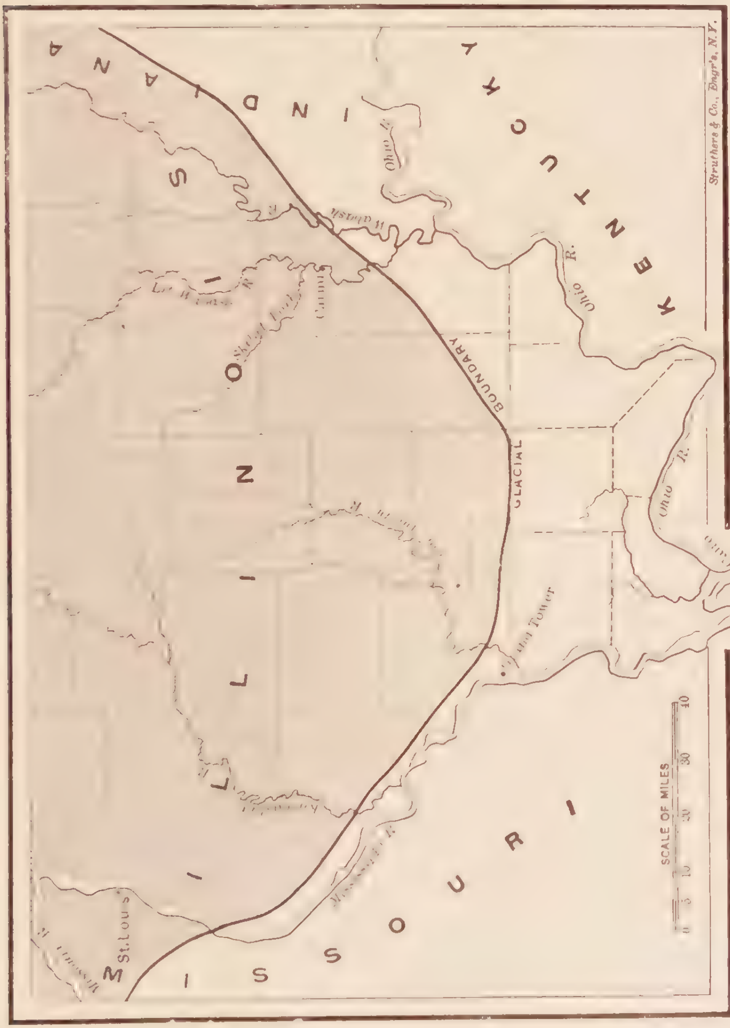

FIG. 58.—Glaciated region of southern Illinois.

ing the vicinity of Oahe, a few miles above Pierre, at the mouth of Bad River. From this point to the mouth of the Cheyenne glacial deposits do not encroach upon the plateau to the west. But, above the mouth of the Cheyenne, the line strikes off farther west, and crosses the Moreau River about forty-five miles back from the Missouri, and the Grand and Cannonball Rivers at about the same distance. The Northern Pacific Railroad passes from the glaciated to the unglaciated region at Sims Station, about thirty miles west of Bismarck.

In the chapter upon "Terminal Moraines" we will speak more fully of the portion of Dakota lying east of the Missouri River; but west of the Missouri the deposits belong to what we have denominated the *fringe*, or what President Chamberlin perhaps more appropriately calls "the attenuated border." This portion of the boundary I had the privilege of studying in the summer of 1888, driving some hundreds of miles through the Indian reservation, extending from Fort Yates southwestward to the Moreau, and thence southeastward to the vicinity of Pierre. Here I found the border, although somewhat attenuated, to be pretty sharply defined. The glacial marks, however, consisted almost wholly of bowlders and rather coarse gravel, and was pretty evenly distributed over the surface of the plateau. The formation of the region is cretaceous, so that it is easy to recognize the Laurentian bowlders. In size these sometimes attain a diameter of four or five feet, and frequently almost cover the ground. The elevation attained by them runs up to about six hundred feet above the river. We found, however, no scratches upon these bowlders, nor were there any exposures of till or unstratified deposit, so characteristic of the terminal moraine and of the central portion of the glaciated area. But from my own experience I have no hesitation in classifying these deposits with those produced by direct action of the glacier. They are what would naturally occur on the attenuated margin of the ice-sheet.

I found evidence, also, of a temporary line of marginal

drainage, which consisted of a broad, level-topped gravel deposit from four hundred and fifty to five hundred feet above the present bed of the Cheyenne River.* This old river-bottom is about two miles wide, and, where we crossed it, extended as far as the eye could reach both up and down the valley. Subsequently Mr. Riggs found that it joined the valley some miles above from the northwest. The gravel is rather fine and well worn, and there is only an occasional bowlder from one to two feet in diameter to be found upon the surface. On the higher levels there are no traces of the deposit. It has, therefore, as already said, the appearance of marking a marginal line of drainage, which, north of the Moreau River, was thirty or forty miles west of the Missouri, but which joined the Cheyenne just west of Fox Ridge, and followed that valley down to the vicinity of the Missouri, and ever after kept near its trough till the river passed out of the Territory at the Nebraska line.

Soon after crossing the Northern Pacific Railroad in Dakota, the glacial boundary turns abruptly to the west, crossing the Yellowstone in Montana near Glendive. We give the delineation beyond this point in the words of President Chamberlin:

"Passing north of the Judith Mountains, it again touches the Missouri in western Montana, near the mouth of the Judith River, but at once swings away to the southward, to again strike and cross the river forty miles above Fort Benton, and about the same distance from the Rocky Mountains. Thence it curves rapidly to the northward, crossing the national boundary at the very foot-hills, and thence skirts them northward to the limits of present determination. This is the outline of the great northeastern sheet of drift. Along the Rocky Mountains, within the United States, it barely comes in contact with demonstrable glacial formations from the adjacent mountains, though widely intermingled with mountain 'wash.'" †

* The elevations are kindly furnished me by Rev. Thomas L. Riggs, of Oahe

† "Proceedings of the American Association for the Advancement of Science," vol. xxxv, 1886, pp. 196, 197.

In the chapter upon "Terminal Moraines" we will speak of the extension of the Missouri coteau into British America, as determined by Dr. George M. Dawson. But, while this coteau is the limit of the heavier accumulations of Laurentian drift, it is evidently not the limit of the extent of glacial ice, for over an indefinite border to the west of it there is, according to Dr. Dawson, a large percentage of Laurentian material, amounting to nearly fifty per cent of the surface accumulations, mingled with about the same proportion of quartzite drift brought down from the Rocky Mountains by the numerous streams originating in them. Dr. Dawson says that these Laurentian and eastern limestone bowlders continue to occur to within twenty-five miles of the base of the Rocky Mountains, and up to a height of 4,200 feet above tide. The distance of these traveled blocks from the nearest part of the Laurentian region is about 700 miles. Beyond this point, to the west, eastern and northern rocks are not found. The elevation of this marginal drift is about 2,000 feet above the present height of the Laurentian plateau from which it came.*

"To the westward, in the valleys of Flathead, Pend D'Oreille, and Osoyoos Lakes, and of Puget Sound, are massive deposits of drift, partly of northern and partly of local mountainous derivation. The Pend D'Oreille and Puget Sound deposits appear unquestionably to be tongues of the drift of British Columbia, which, if not constituting a continuous mantle, at least passes beyond the character of simple local mountain drift." †

In the Rocky Mountain region and to the westward there were formerly extensive glaciers in Montana, Wyoming, Colorado, Utah, Nevada, and California, where now they are almost entirely absent. But the glaciation of this region was never general. According to Whitney, there are no signs of ancient glaciers in western Nevada, though some of the mountains rise to a height of 10,000 feet. In the east Hum-

* See the "Quarterly Journal of the Geological Society," vol. xxxi, 1875.

† See Chamberlin, as above.

boldt range, local glaciers once existed in all the higher portions. In some of the valleys they extended for seven or eight miles. In Utah the Wahsatch Mountains were the chief center of local glaciers. The principal mountain-mass is about fifteen miles wide, and peaks above 10,000 feet high are numerous. The glaciers formerly radiating from this mass did not, however, reach a very low level. In Colorado there are evidences of former glaciers only above the 10,000-foot line. Beyond that line, such valleys as those occupied by the head-waters of the Platte and Arkansas Rivers were once filled with glaciers whose terminal moraines, in some cases, formed dams of great extent, and thus gave rise to temporary lakes. The most southern point at which signs of local glaciers in the Rocky Mountains have been noted is near the summits of the San Juan Range in southwestern Colorado. Here a surface of about twenty-five square miles, extending from an elevation of 12,000 feet down to 8,000 feet, shows every sign of the former presence of moving ice. Northward of Utah and Colorado the signs of former glaciation are also of the same local character—that is, glaciers everywhere radiated from the higher mountain-masses, and extended a short distance down the cañons and valleys. The Upper Cañon of the Yellowstone, in the famous park, was filled with glacial ice to a depth of 1,600 feet, and glacial marks were abundant down to the vicinity of Livingston.

The glaciers of the Sierra Nevada and Cascade Range in California, Oregon, and State of Washington were on a much grander scale than those in the Rocky Mountains; but, in the one case as in the other, the glaciated areas are local, and, except in the state of Washington, not connected with the grand movement farther north.

Upon this point Mr. Clarence King, who had most carefully explored the region, writes:

In the field of the United States Cordilleras, we have so far failed to find any evidence whatever of a southward-moving continental ice-mass. As far north as the upper Colum-

bia River, and southward to the Mexican boundary, there is neither any bowlder-clay nor scorings indicative of a general southward-moving ice-mass. On the contrary, the great areas of Quaternary material are evidently subaërial, not subglacial. The rocks outside the limit of local mountain glaciers show no traces either of the rounding, scoring, or polishing which are so conspicuously preserved in the regions overridden by the northern glacier. Everything confirms the generalization of Whitney as to the absence of general glaciation.

Wherever in the fortieth parallel area a considerable mountain-mass reached a high altitude, especially when placed where the Pacific moisture-laden wind could bathe its heights, there are ample evidences of former glacial action, but the type is that of the true mountain glacier, which can always be traced to its local source. In extreme instances, in the Sierra Nevada and Uintah Ranges, glaciers reached forty miles in length, and, in the case of the Sierra Nevada, descended to an altitude of 2,000 or 2,500 feet above sea-level. Over the drier interior parts of the Cordilleras the ancient glaciers usually extended down to between 7,000 and 8,000 feet above the sea. In the case of the Cottonwood Glacier of the Wahsatch, a decided exception, the ice came down to an altitude of 5,000 feet. . . .

Not more than a thirtieth part of the entire surface of the fortieth parallel area was ever covered by glacial ice. It is characteristic of the cañons of these extinct glaciers that they give evidence of a gradual recession of the ice from its greatest extension until it is entirely melted. This retiring from its greatest bulk was not a continuous retrogression, but was marked by pauses at certain places long enough to permit the accumulation of considerable terminal moraines. In ascending one of the larger cañons, as of the southern Uintah, there is observed a series of successive terminal moraines, and in passing to the upper heights of the ranges it is found that, in the great snow amphitheatres, glacial markings, rock-polishing, and the arrangement of morainal matter are evidently fresher than in the lower levels or points of greatest extension.

Whatever the greater causes may have been, the Cordilleran surface south of the State of Washington was free from an ice-

sheet, and the only ice-masses were small areas of local glaciers which did not cover two per cent of the mountain country.

Supposing the arctic land configuration to be as now, and a new oscillation of climate to bring on the conditions of a glacial period, it is certain that the present ice-masses would form the nuclei of new northern ice-fields, and Greenland would probably be the point from which the glaciers would move southward to cover eastern America; and the absolute distance from such a center would have something to do with the failure of the ice to override the Cordilleras. Dawson's suggestion of a great center of dispersion in Alaska, where an elevated and broad highland fronts the moisture-laden ocean-wind, has, it seems to me, a high degree of probability in accounting for the southerly-moving ice of British Columbia without recourse to that refuge of pure imagination, a polar cap.*

With this agrees the testimony of Mr. I. C. Russell, in his report on the "Quaternary History of Mono Valley, California," the advance sheets of which I have been kindly permitted to see. He writes:

The Sierra Nevada during the Glacial epoch was covered by an immense *névé* field, which probably stretched continuously from a little north of latitude 36° nearly to latitude 40°. The width of this belt of perpetual snow must have been irregular, conforming to the present topography of the summit of the range, but it probably had an average width of between ten and fifteen miles. From beneath this snowy mantle trunk glaciers flowed both east and west down the flanks of the range.

The evidence is such as abundantly to justify the conclusion that the ancient glacial system of the Sierra Nevada was local, and had no connection with a northern ice-sheet. The glaciers were clustered about and radiated from the higher portion of the range in the same manner as from the contemporary *névé* fields of the Wahsatch and Uintah Mountains.†

* "Systematic Geology" in the "United States Geological Exploration of the Fortieth Parallel," 1878, pp. 459–461, 464.

† See the "Eighth Annual Report of the United States Geological Survey," pp. 327, 328.

The ancient area of glaciers in the Sierra Nevada Mountains was chiefly confined to the western slope, and was most remarkable in Tulare, Fresno, Mariposa, and Tuolumne counties, California, where, as we have seen, glaciers still continue to exist. There are abundant marks of these ancient ice-streams in the upper valleys of Kings, San Joaquin, Merced, and Tuolumne Rivers. In the Tuolumne the glaciers were in some places several miles wide and twelve hundred feet deep, and extended as much as forty miles down the valley. Glaciers likewise filled the Yosemite Valley on the Merced River. It is a mistake, however, according to Whitney, to suppose that the Yosemite was formed, or indeed greatly modified, by glacial action.* The vertical walls and the rectangular recesses are such as to indicate the action of disruptive rather than erosive agencies in their formation.

The north-and-south valley between the Cascade Mountains and the Coast range, in the State of Washington, is about one hundred miles wide. The northern half of this is penetrated by the innumerable channels and inlets of Puget Sound, which extends from Port Townsend south about eighty miles to the parallel of Mount Tacoma. The Olympian Mountains to the west rise to a height of about ten thousand feet, as does Mount Baker in the Cascade Range to the northeast. The shores and islands of Puget Sound have every appearance of being portions of a vast terminal moraine. They rise from fifty to two hundred feet above tide, and present a mixture of that stratified and unstratified material characteristic of the terminal accumulations of a great glacier. No rock in place appears anywhere about the sound. Bowlders of light-colored granite and of volcanic rocks are indiscriminately scattered over the surface and imbedded in the soil. One of these bowlders, near Seattle, two hundred feet above the sound, measures twenty feet in diameter, and twelve feet out of ground. The channels of the sound and

* "The Yosemite Guide-Book," p. 83. See also the opinion of Mr. Russell given near the close of Chapter X.

of the adjacent fresh-water lakes have a general north-and-south direction, parallel with the axis of the valley. This is specially noticeable near Seattle, where Lake Washington,

FIG. 59.—Typical section of till in Seattle, State of Washington, about two hundred feet above the sound. This is on the height between the sound and Lake Washington.

elevated sixteen feet above tide, and twenty-five miles long, is strictly parallel with the sound, and is separated from it

by a series of ridges showing every mark of glacial origin. Not only is the surface of these ridges covered with bowlders, but wherever the streets have cut down into the soil they show, at the depth of a few feet, an unstratified deposit abounding in striated stones. Superimposed upon this ridge there is a thin stratified deposit of varying depth, but increasing in extent down the slope toward tide-water.

At Port Townsend, on the Strait of Juan de Fuca, and forty miles northwest of Seattle, the coarsely stratified deposit is much greater in extent. A noteworthy section of this I had the privilege of studying at Point Wilson, two miles and a half northwest of Port Townsend. Here, facing

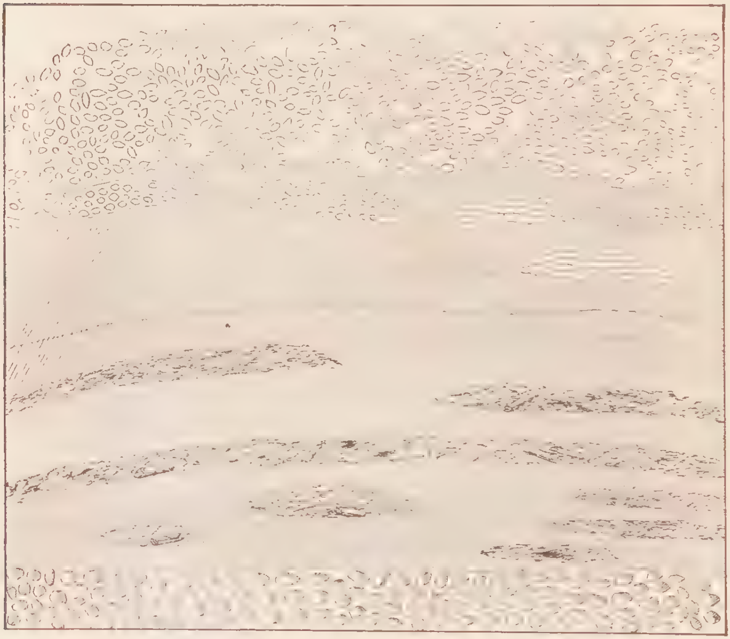

FIG. 60.—Section of the deposit at Point Wilson described in the text, showing one hundred and fifty feet in height, about one hundred of which is coarsely stratified, and contains layers of vegetable matter. Bowlders from till at the top have fallen down to form a talus at the water's edge.

the strait toward the north, is a perpendicular bluff from one hundred and fifty to two hundred feet in height, composed

of material coarsely stratified throughout its lower portion, but capped at the summit by about forty feet of coarse, unstratified material abounding in large striated bowlders, which, as they have been washed out by the erosion of the sea, are falling down to the foot of the bluff in immense numbers. Near the bottom of the bluff there are several strata of vegetal deposits. One of these, two feet thick, consisted almost wholly of the fragments of the bark of the fir-trees which are now so characteristic of that region. Fragments of wood project from the freshly exposed bank in great abundance. The meaning of these facts will be more readily apparent after a study of the phenomena to the north of the strait.

The Strait of Juan de Fuca is from fifteen to twenty miles in width, setting in from the Pacific Ocean and running east and west. Its north shore, near Victoria, on Vancouver Island, is remarkably clear of glacial *débris.* The rocks, however, near Victoria, exhibit some of the most remarkable effects of glacial scoring and striation anywhere to be found. Immediately south of Victoria long parallel furrows rise from the shore of the inlet, and ascend the slope of the hill to the south to its summit, a hundred feet or more above the water-level. At the steamboat-landing, outside of the harbor, extensive surfaces freshly uncovered exhibit the *moutonnée* appearance of true glaciation, and, in addition to the finer and abundant scratching and striae, display numerous glacial furrows from six inches to two feet in depth, from twenty to thirty-two inches in width, and many feet in length. These grooves are finely polished and striated, resembling those with which geologists are familiar on the islands near the the western end of Lake Erie. Like the corresponding grooves on the islands of Lake Erie, some of those near Victoria also form graceful curves, adjusting themselves to the retreating face of the rock-wall. That the motion of the ice at Victoria was to the south appears not only from the direction of the striae, but from the fact that the stoss sides of the glaciated rocky projections are toward the north. That they are due to glacial action, and not to ice

FIG. 61.—Glacial groovings near the landing at Victoria (see text). (From Photograph.)

bergs, is evident both from their character and from their analogy to numerous phenomena farther to the north unquestionably connected with true glaciers.

Speaking of Vancouver Island and the adjacent region, the Scotch geologist, Robert Brown, uses the following language:

> The chief rock *in situ* there is a dense, hard, feldspathic trap, and this is plowed in many places into furrows six to eight inches deep and from six to eighteen inches wide. The ice-action is also well shown in the sharp peaks of the erupted, intruded rocks, having been broken off and the surface smoothed and polished, as well as grooved and furrowed, by the ice-action on a sinking land, giving to the numerous promontories and outlying islands which here stud the coast the appearance of rounded bosses, between which the soil is found to be composed of sedimentary alluvial deposits, containing the *débris* of tertiary and recent shelly beaches, which have, after a period of depression, been again elevated to form dry land, and to give the present aspect to the physical geography of Vancouver Island.
>
> The whole surface of the country is strewn with erratic bowlders. Great masses of sixty to one hundred tons in weight—chiefly of various igneous and crystalline as well as sedimentary rocks, sufficiently hard to bear transportation—are found scattered everywhere over the island from north to south, and through the region lying on the western slope of the Cascade Mountains.*

The same observer thus speaks of the glacial phenomena on the mainland in the same vicinity:

> The following section is given to show the general character of the drift at Esquimault Harbor:

Black sandy and peaty ground, with broken shells	2 to 6 feet.
Yellowish sandy clay, with casts of shells (Cardium and Mya) and a few pebbles and bowlders	6 to 8 "
Gravel of scratched pebbles resting on rock.	2 to 3 "

> The rocks are grooved and scratched at the junction; the direction of the glacial markings is between north to south and north-northwest to south-southeast. In a well-sinking, at

* "American Journal of Science," vol. c, 1870, pp. 320, 321.

Esquimault Barracks (for the boundary commission), the lower gravel was reached at forty-two feet, after going through a sandy-blue clay without shells or bowlders. The section in the cliff between Albert Head and Esquimault is as follows:

Blue drift clay, with bowlders; junction with rock not seen	70 feet.
Fine sand and gravel, passing upward into coarse quartzose gravel	100 to 120 feet.*

I saw at Seahome (near Bellingham Bay), in the cuttings made for a tramway, the finest instances of fluting and grooving—evidences of glacial action—that I have ever seen on this coast. They were ninety feet in length, running north and south, according to the theory of Professor Agassiz. †

Vancouver Island, which trends parallel with the shore of the continent northwest by southeast, is nearly three hundred miles in length and from fifty to seventy-five in breadth. In character it seems but a continuation of the Coast Range of mountains, with numerous peaks rising from four to seven thousand feet above the sea. The shore-line of the continent upon the northeastern side of the Strait of Georgia is formed by a continuation of the Cascade Range, with a general elevation of from three to eight thousand feet, and is penetrated in numerous places, to a distance of from twenty-five to seventy-five miles, by inlets or fiords some miles in width. Dr. George M. Dawson describes the glacial phenomena in Bute Inlet (which enters the Strait of Georgia about opposite the center of Vancouver Island, in latitude 50° 30′) in the following language:

This chasm, forty miles in length, and running into the center of the Coast Range, is surrounded by mountains, which in some places rise from its borders in cliffs and rocky slopes to a height of from six to eight thousand feet. It must have been one of the many tributaries of the great glacier of the Strait of Georgia, and accordingly shows evidence of powerful

* "Quarterly Journal of London Geological Society," 1860, p. 202.

† "American Journal of Science," vol. c, pp. 322, 323.

ice-action. The islands about its mouth are *roches moutonnées*, polished and ground wherever the original surface has been preserved. In Sutil Passage, near its entrance, grooving appears to run about south 30° west. A precipitous mountain on Valdez Island, opposite Stuart Island, and directly blocking the mouth of the inlet, though 3,013 feet high, has been smoothed to its summit on the north side, while rough toward the south. The mountain-side above Arran Passage shows smooth and glistening surfaces at least two thousand feet up its face; and, in general, all the mountains surrounding the fiord present the appearance of having been heavily glaciated, with the exception of from one to two thousand feet of the highest peaks. The high summits are rugged and pointed, and may either never have been covered by glacier-ice, or owe their different appearance to more prolonged weathering since its disappearance. In some places parallel flutings high up the mountain-sides evidence the action of the glacier, while in others it is only attested by the general form of the slopes, or detected under certain effects of light and shade. . . . At the mouth of the Howatheo River, discharging into the head of Bute Inlet, striation shows a direction of movement south 22° east; but in every case the motion appears to have been directly down the valley, and to have conformed to its changes in course. Glacier-ice may still be seen shining bluely from some of the higher valleys at the head of the inlet, and farther up the Howatheo River there are many glaciers in lateral valleys, some of which descend almost to the river-level.

Mr. James Richardson, who has had an opportunity of examining many of the inlets north of Vancouver Island, writes as follows:* "Throughout the whole of the inlets and channels which were examined, wherever the surface of the rock is exposed, the ice-grooving and scratching are very conspicuous, from mere scratches to channels often several feet in width, and from a few inches to as much as two or three feet in depth. Often they can be distinctly seen with the naked eye from the surface of the water to upward of three thousand feet above it on the sides of the mountains. They

* "Report of Progress of the Geological Survey of Canada, 1874–'75," p. 8.

run in more or less parallel lines, and are not always horizontal, but deviate slightly up or down." *

Mr. Robert Brown, whom we have already quoted, gives the following additional information as to regions still farther north :

I have not been in Alaska proper, but in 1866, in a visit to the Queen Charlotte Islands, lying some thirty or forty miles off the northern coast of British Columbia, close to the southern boundary of the former Territory, marks of the northern drift quite as marked as in Vancouver Island were found there.†

As already indicated, the mountains on either side the Strait of Georgia, and northwestward to the head of Lynn Canal, about latitude 59° 20′, are snow-clad throughout the whole season. The shores are everywhere rocky and precipitous, retaining in many places far up their sides glacial striæ parallel with the direction of the numerous channels which thread their way through the Alexander Archipelago. I had opportunity at Loring, on the western shore of Revilla Gigedo Island, to examine minutely the striation on the shores and islands of Naha Bay. There are now no glaciers coming down from the mountains of this island, but the shores and islands abound in well-preserved glacial striæ running west by 18° north, corresponding to the direction of the local valley, down which a glacier came in former times, entering Behm's Canal nearly at right angles to its course upon that side of the island. This is about latitude 55° 40′.

Upon proceeding one degree to the north, I had opportunity also to observe closely the striæ at Fort Wrangel. Here, too, they show the influence of the continental elevation to the east, and are moving outward in a westerly direction toward the Duke of Clarence Strait.

In Glacier Bay the evidence of the recent vast extension of the glaciers down the bay, and of the facility with which

* "On the Superficial Geology of British Columbia," in the "Quarterly Journal of the Geological Society," vol. xxxiv, February, 1878, pp. 99, 100.

† "American Journal of Science," vol. c, p. 323.

glacial ice adjusts itself to the local topography, is, as already stated, of a most explicit character.* In addition to the evidence already mentioned, we may add that numerous islands project from the surface of the Muir Glacier, as from the waters of an archipelago, and that the summits of these bear every mark of having been freshly uncovered by the decreasing volume of ice. Also that below the mouth of the glacier numerous islands in the bay present exactly the same appearance, except that they now project from water instead of ice. Their recent glaciation is indicated by every characteristic sign. Willoughby Island, about the middle of the bay, is as much as a thousand feet above the water. Were the ice to retreat a few miles farther back from its present front, it would doubtless uncover an extension of the bay, with numerous islands similar to those now dotting its surface south of the glacier. Fresh glacial *débris* lingers on the flanks of the mountains on either side of the inlet, to a height of 2,000 feet. The fact is also worth repeating and emphasizing that at 3,700 feet above tide striæ were observed, on the east side of Muir Inlet, not pointing down the mountain, as might be expected, but parallel with the axis of the bay, showing, beyond controversy, that the present glacier is but a remnant of an earlier ice-movement, similar in character and direction to the present, but of vastly greater dimensions, and which extended until it filled the whole bay to its mouth in Cross Sound, a distance of twenty-five miles. At Sitka, also, the rocks of the harbor are all freshly striated—the direction of the striæ being toward the west—that is, toward the open sea. Glaciers still linger in the mountains at the head of the bay to the east of Sitka.

The absence of glacial phenomena north of the range of mountains, which forms the southern boundary of Alaska, and over the adjacent plains of Northern Siberia, completely disproves the once current theory that the glacial period was characterized by a vast ice-cap extending in all directions

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* See above, p. 56 *et seq.*

from the pole. For, in both these regions, though the soil is frozen to a depth of several hundred feet, there are no indications of the presence of moving ice. Stagnant ice, however, in many places takes the place of ordinary rocks. The expedition of Dawson to the Yukon in 1887 and that of Schwatka and Hayes around Mt. St. Elias in 1892 demonstrated an actual northward movement of ice. Dawson writes:

In the Lewes and Pelly Valleys, traces of the movement of heavy glacier-ice in northward or northwestward directions, were observed in a number of cases, the grooving and furrowing being equally well marked at the water-level and across the summits of hills several hundred feet higher. The facts are such as to lead to the belief that a more or less completely confluent glacier-mass moved in a general northwesterly direction, from the mountainous districts south of the southern sources of the Yukon, toward the less elevated country which borders the lower river within the limits of Alaska. This observation, taken in connection with the evidence of the former northward movement of glacier-ice in the arctic regions to the east of the Mackenzie, appears to have very important bearings on theories of general glaciation.†

From all these facts it seems evident that the supposition of a slight intensification of the present conditions so favorable to the production of glaciers in southeastern Alaska, unravels the whole intricate web of glacial phenomena upon the western coast of North America.

The present formation of glaciers on the coast of southeastern Alaska is favored not so much by the coolness of the climate as by the elevation of the mountains and the excessive amount of precipitation, which, as before stated, is not far from one hundred inches annually. There is no evidence that the elevation of the coast has materially changed in recent times. But it would require only a slight change in the amount of precipitation, or a slight diminution of tem-

* "Science," vol. xi, 1888, p. 186; "Geological Magazine," vol. lxx, p. 347 *et seq.*

† "Annual Report of the Geological Survey," 1886, p. 56, R.

perature, to secure all the additional force required to extend the present glaciers of southeastern Alaska, British Columbia,

Fig. 62.—Map of area covered by the North American ice sheet of the Pleistocene epoch at its maximum extension, showing the approximate southern limit of glaciation, the three main centers of ice accumulation, and the driftless area within the glaciated region. It is now proven that the maximum advance from the Keewatin center preceded that from Labrador; since bowldery deposits from the northeast extend over those from the northwest throughout a large part of Indiana and Illinois and for quite a distance into Iowa. Lake Superior copper is found in the oldest deposits in Pennsylvania, while red jasper conglomerate bowlders from Lake Huron are found in the newer deposits west of the Mississippi a few miles from Keokuk.

(From the United States Geological Survey.)

and of the Cascade Range of State of Washington and Oregon, until they should gorge all the channels of the Alex-

ander Archipelago, fill the space occupied by the Strait of Georgia between Vancouver Island and the mainland, and cover with ice the whole valley between Mount Tacoma and the Olympian Mountains, where now we find the vast moraine deposits of the islands and shores of Puget Sound.

A simple calculation impresses one with a sense of the unstable equilibrium of the forces leading to the increase or diminution of a glacier. We estimated that 77,000,000,000 cubic feet of ice annually pass through the gorge at the head of Muir Inlet, and that the area of the ice-field supplying this stream is about twelve hundred square miles. The total amount of ice entering the inlet, therefore, is only equivalent to about two feet of ice over the field of supply. If from any cause two feet more of ice should annually accumulate over this area, or two feet less should annually melt away, the amount of ice compelled to go through the gorge would be doubled, and this would doubtless fill up the whole inlet and bay to the south. When we reflect that, according to Newcomb,* the average amount of ice which would be melted by the sun over the whole earth is something more than a hundred feet a year, and that, therefore, a change in intensity amounting to only one fiftieth of that exhibited by the present meteorological forces would produce the results just mentioned, we can readily believe that oscillations in such a great glacier may be frequent in occurrence and of great magnitude.

Southward, in Oregon, the Willamette Valley was filled in a similar manner by an extension of the glaciers still lingering on the flanks of Mounts Hood and Shasta. The absence of drift on the southern shore of Vancouver Island seems to point to a termination of the southerly movement from Alaska in the Strait of Juan de Fuca, where perhaps the confluent streams turned westward, and sent off vast drift-laden icebergs to the sea. Mount Baker, immediately to the east of this point, upward of ten thousand feet high,

* "Popular Astronomy," p. 247.

and still preserving glaciers on its flanks, would have lent material aid in this seaward movement. The shores and islands about Puget Sound have the appearance of being the terminal deposits of confluent glaciers coming down from the flanks of Tacoma on the southeast, and from the lower portions of the Cascade Range farther north, joined by smaller glaciers from the Coast Range on the west. It is clear that the earlier glacial movements on the Pacific coast were local in character, and must be studied independently of those east of the Rocky Mountains, and can be understood only by reference to the glaciers which still linger at the head of all its numerous valleys, inlets, and fiords. In these the investigator has a *vera causa* ever before his eyes to guide his steps and to assist his imagination.

CHAPTER VIII.

DEPTH OF THE ICE DURING THE GLACIAL PERIOD.

There are two sources of information concerning the depth attained by the ice in North America during the Glacial period: First, we have direct evidence in the height of the mountains which have marks of glaciation upon their summits; secondly, calculations can be made, with some approximation to truth, from the distance through which bowlders have been transported.

Very conveniently for the glacialist, the mountains of New England and the Middle States serve the purpose of glaciometers, preserving upon their flanks and summits indubitable evidence of the great depth of the ancient ice-sheet over that portion of the country.

It requires but a cursory examination to see that the highest point of Mount Desert Island, on the coast of Maine, was completely covered by the glacier, showing that at the very margin of the ocean the ice must have been considerably more than 1,500 feet deep. Even Mount Washington, in New Hampshire, was either wholly enveloped by the ice-current, or if a pinnacle projected above the glacier it could have been no more than 300 or 400 feet higher, Professor Hitchcock having found transported bowlders to within that distance of the summit. The ice-current passed over the Green Mountains where they are from 3,000 to 5,000 feet in height in a course diagonal to that of their general direction, showing that such a mountain-chain made scarcely more of a ripple in the moving mass than a sunken log would make in a shallow river. Farther south, Mounts Monadnock, Tom,

and Holyoke, the Berkshire Hills, and East and West Mountain, near New Haven, were also completely enveloped in ice. Between the Adirondacks and the Alleghanies the Mohawk Valley was filled nearly to the height of the Catskills, and the southern edge was pushed up in Monroe, Sullivan, Tioga, and Potter counties, Pa., to a height of 2,000 or 2,500 feet above the sea.

In remarking upon the accompanying sections, Professor Lesley, who made them, says that while they do not satisfy him in several important particulars, such as the regularity of its surface, the location of possible crevasses, the descent into the plain, the distribution of bowlders, etc., they serve to give a correct generalized view—first, of the great thickness of the ice-sheet, by contrasting it with the sections of the solid rocks from the present surface down to the plane of sea-level; second, to allow the reader to judge for himself of the extent of the eroding power at this point. We append Professor Lesley's reasons for constructing the scale as he has:

As to the first point, I have given to the surface of the ice a gentle slope southward, by making it 600 feet thick over the mountain, and 1,800 feet thick over Cherry Creek; which slope, if continued northward, would suffice to make the ice cover the highlands (2,000 feet above tide) farther north, as we know that it did. Thirty years ago Agassiz gave me his law of the necessary *minimum thickness of a glacier for crossing a barrier.* It was in a conversation immediately subsequent to his study of the striæ on the top of Mount Desert, pointing from Mount Katahdin, and descending into the sea. He said that no glacier could cross a ridge unless its thickness at the summit of the ridge was *at least one half the height of the ridge.* By this rule he judged that the ice-sheet of Maine was 750 feet thick over the top of Mount Desert; and this would account for the great distance south of Mount Desert of the terminal moraine.

This rule was obtained by Agassiz and Desor in their long residence on the glacier of the Aar, and was based on numerous observations of local Alpine glaciers where they were crevassed

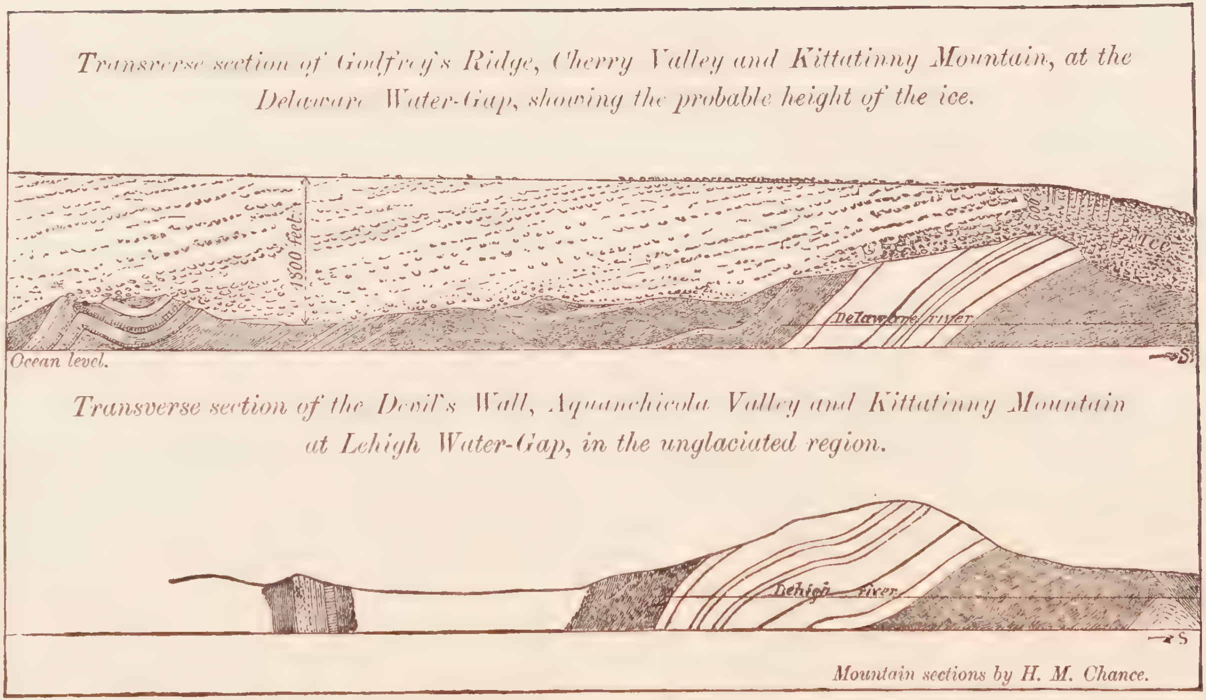

FIG. 63.—Idealized view by Professor Lesley, showing the depth of the ice, the direction of the movement of bowlders, and the amount of erosion in eastern Pennsylvania, described fully in the text.

in surmounting barriers of rock. Whether it is a rule to hold good under quite different circumstances, in the case of continental ice-sheets, or not, we have no means of knowing; but it is the only rule at our command. I have applied it to the case of the Kittatinny Mountain, and made the ice-sheet 600 feet thick where it crossed the crest. It may have been any amount thicker for all we know.

The two sections given in this plate were constructed by H. M. Chance, some years ago, after special topographical surveys and contour-line maps had been made by him at the Delaware, Lehigh, and Schuylkill Water-Gaps. They are published in Reports G^6 and D^3, with the maps to which they belong.

I have added to the north end of the upper section one of the transverse sections of Godfrey's Ridge, south of Stroudsburg, which I made in 1840, in order to show the outcrops of Oriskany sandstone and Lower Helderberg limestone from which the bowlders were taken by the ice which now lie on the Kittatinny Mountain.

Mr. Lewis remarks, on page 91, that "almost every block of limestone that was taken from the Helderberg Ridge in Cherry Valley can be traced to its destination"; and on page 88 he directs special attention to the large numbers and great sizes of them which were carried across Cherry Valley and left perched upon the top of Red Ridge overlooking Wolf Hollow; and to one which he found on the very summit of the Kittatinny Mountain, at an elevation of 1,200 feet above the outcrop in Godfrey's Ridge.*

In the earlier reports upon the mountain-region of northeastern Pennsylvania, it was concluded by Professors I. C. White and H. C. Lewis that the ice in that part of the State had not surmounted elevations more than 2,220 feet above tide. But Professor J. C Branner, on re-examining the region in the summer of 1886, found distinct glacial marks upon the summit of Elk Mountain, in Susquehanna county, 2,700 feet above tide; while the whole range of Lackawanna

* "Second Geological Survey of Pennsylvania," vol. Z, p. xiv

Mountains, northeast of the Susquehanna Gap at Pittston, showed distinct signs of glaciation on their highest summits, which are from 2,000 to 2,200 feet above tide. This would give a depth of 1,500 feet in the Susquehanna Valley in that neighborhood.*

The most formal attempt to estimate from known data the depth of the ice near its ancient margin is that by Professor J. C. Smock, in a paper † before the American Association for the Advancement of Science at Montreal. Professor Smock finds definite evidence in northern New Jersey of a depth of only about seven hundred feet to the ice, though it is impossible to say that it was not more. For example, the highest points of Schooley's Mountain table-land consist of moraine hills from twelve to thirteen hundred feet above tide, while the Musconetcong Valley to the west, which the ice had to fill before it surmounted the elevations indicated, is seven hundred feet lower, showing that the ice must at that point have been in the neighborhood of a thousand feet in thickness. Professor Smock was also the first one to ascertain that Pocono Mountain, in Monroe county, Pa., showed signs of glaciation up to a height of over two thousand feet. From the study of the glacial phenomena of that region, Professor Smock correctly infers that "the inclination of the continental ice-sheet of the Glacial epoch was not uniform. The rise was probably steep near the margin. . . . Thus, near Feltville and Summit, the drift-covered Springfield Mountain, which is about a mile north of the line, is nearly six hundred feet high. The high drift-hills near Mount Hope (960 feet) [also] show a great thickness near the margin. . . . Northward the angle of the slope diminished, and the glacier surface approximated to a great level plain. The distance between the high southwestern peaks of the Catskills and Pocono Knob in Pennsylvania is sixty

* "The Thickness of the Ice in Northeastern Pennsylvania during the Glacial Epoch," by J. C. Branner, in the "American Journal of Science," vol. cxxxii, 1886, pp. 362–366.

† "American Journal of Science," vol. cxxv, 1883, p. 339 *et seq.*

miles. The difference in the elevation of the glacier could not have exceeded a thousand feet. In that direction the slope was less than on a meridian line from the Catskills southward."

Professor Dana estimates that the height of the ice "above the region of New Haven, in southern Connecticut, may have exceeded two thousand feet, and could hardly have been less than fifteen hundred."

So far the evidence is direct and positive, because the glacial marks are left upon the mountain-summits mentioned. How far still above these summits it rose is not so easily determined. From this amount of direct evidence it may also reasonably be inferred that the depth of the ice over the lake and prairie region of the West was equally great. If our interpretation of the facts implying the presence of an ice-sheet in North America is correct, we have also positive evidence of a great depth of ice over the central portion of British America between Hudson Bay and the Rocky Mountains. Here we find, according to Dawson, that bowlders from the Laurentian axis of the continent, which stretches from Lake Superior northward to the west of Hudson Bay, have been transported westward a distance of seven hundred miles, and left upon the flanks of the Rocky Mountains at an elevation of something over four thousand feet.* But nowhere does the Laurentian axis reach two thousand feet, its average elevation, according to Sir William Logan, being from fifteen to sixteen hundred feet. If these bowlders were, as we suppose, transported by glacial ice, then the ice must have accumulated over the Laurentian axis to a depth of 2,400 or 2,500 feet, and must have been several hundred feet deeper in the central part of the Red River Valley. Mr. R. G. McConnell, of the Canadian Survey, also, from more direct evidence, estimates † that, in the plains surrounding the Cypress Hills (in the upper valley of the South Saskatchewan, in latitude 49° 30′, longitude 110°, and not

* See p. 214. † See his "Report on the Cypress Hills Wood Mountain."

more than one hundred miles from the southwestern limit of the glaciated area in Montana), the continental glacier, or the glacial sea, according to which one of the theories of transportation is adopted, had a maximum depth of two thousand feet. This he determines by the height to which he found glacial deposits resting upon the Cypress Hills. It is the necessity of accounting for such an elevation of bowlders in glacier-ice which has made the Canadian geologists hesitate about accepting the glacial theory. It seemed to them at first more probable that there had been a depression of about four thousand feet in the Rocky Mountain region, and that these bowlders were transported from the Laurentian axis by floating ice. We think, however, that such facts as are illustrated in the diagram of Professor Lesley's on page 196, as well as other facts yet to be stated concerning the elevation of bowlders in ice, go far to remove the objections to the glacial theory urged by the Canadian geologists, and we therefore speak with considerable confidence of the great depth of the ice over the Laurentian axis. The glacial theory, moreover, as Dr. Dawson frankly and early admitted, relieves them of many difficulties in accounting for the noticeable absence of other indications of subsidence in the region under consideration. For example, there is, first, according to Dr. Dawson,* a complete absence of any marine animal remains in the drift over that region; and, secondly, "the yielding, scarcely solidified" sediments over this vast region bear slight evidence of any such great change in elevation.

The great depth of the ice over the lake-region during the Glacial period is also evident from the second mode of calculation, namely, that based upon the distance over which bowlders are known to have been transported by the direct movement of the ice. The fluidity and plasticity of ice are so slight that, where we find it moving hundreds of miles over a level country, the thickness at the starting point can scarcely

* "Report on the Forty-ninth Parallel," as above, pp. 216, 244, 260, *et al.*

have been less than that indicated by the evidence in New England. Over southern Ontario and Michigan, and over the larger part of Wisconsin, Minnesota, northern Illinois, and Iowa, the ice must have been thousands of feet in depth, or it never could have pushed southward to the latitude of Cincinnati, Louisville, and St. Louis.

The uncertainties attending this mode of calculation are, however, very great, and it can be taken only for approximate results. In the Alps the lowest mean slopes down which glaciers move are $2\frac{1}{2}°$ to $3°$, or about 250 feet to the mile. But, as Professor Dana notes,* the thickness of the ice there is not over 500 feet. Mathematicians are not able to deal successfully with the problems of friction in viscous bodies. How such a body will behave in greatly increased masses can be determined only by experiment. In Greenland, where the thickness of the ice more nearly approaches that of the ice-sheet formerly covering the northern part of the United States, Jensen found the slope of the Frederikshaab Glacier to be 0° 49′, or about seventy-five feet a mile; while Helland found the slope of the Jakobshavn Glacier to be only 0° 26′, or about forty-five feet to the mile.† This latter slope of the surface of the continental glacier would, if continuous, make the thickness of the ice 10,000 feet over northern New England, and about 11,000 feet over Lake Erie, while the depth of the ice in this calculation over the region north of Lake Huron and Lake Superior, from which certain bowlders in Kentucky came, would be nearly 30,000 feet, since the distance moved is 600 miles or more.

Upon the supposition that the slope from the front toward the interior was but half a degree, Croll estimates that the depth of ice at the south pole, at the center of the Antarctic Continent, must be as much as twelve miles. This is on the supposition that the diameter of the continent is 2,800 miles. The same rate of calculation would, according to

* "American Journal of Science," vol. cxxvi, 1883, p. 348.

† "Meddelelser om Grönland," 1879, and "American Journal of Science," vol. cxxiii, 1882, p. 364.

Hitchcock,* require the ice of the Glacial period to be eight miles deep over the central part of Labrador; and, if the movement came from Greenland, the same slope of forty-five feet to the mile would reach, at that point, the astonishing depth of eighteen miles.

It is not necessary, however, to suppose a uniform slope to the center of so vast an ice field. If, however, we assume with Chamberlin and Salisbury,† that there was an actual movement of glacial ice of 1,600 miles from the Labradorian center to the southern part of Illinois, and of equal extent from the Keewatin center west of Hudson's Bay to Topeka, Kansas, an average slope of but ten feet to the mile would give a depth of three miles at the centers. That the depth was as great as this, seems the more probable from the fact that the Keewatin center is low, and unless the elevation of that region was then much greater than it is now the movement must have been produced by the pressure caused by the simple accumulation of ice. Staggering to the imagination as these suppositions are, they seem to be inevitable inferences from the established facts. A depth of three miles over the central portions of the glaciated area in North America is, therefore, by no means improbable.

* "New Hampshire Geological Report," vol. iii, pp. 320, 321.
† Geology, vol. iii, pp. 330, 357.

CHAPTER IX.

TERMINAL MORAINES.

SINCE the word *moraine* originally designates a considerable accumulation of glacial *débris*, it has been found impossible to apply the term to the marginal deposits along the whole boundary; for, as was stated in the chapter treating of the subject, the glacial margin in the Mississippi Valley is not marked by such accumulations as characterize it east of the Alleghanies. The glacial deposits south of New England are, however, truly phenomenal in their extent, and can with perfect propriety be called terminal moraines. Why glacial *débris* should have accumulated to such an extent along that line it is impossible to tell with certainty; but, recurring to the principles already presented, it would seem, not only that such an extensive terminal moraine indicates an abundance of easily disintegrated rock to the north offering itself for transportation in the line of the glacial movement, but that it also indicates that the ice-front remained for a long time stationary in the latitude of New York between Nantucket and the Delaware River. How much the proximity of the ocean may have had to do with the maintenance of this stationary ice-front we may never fully determine; but, both by its natural effect in eroding the advancing ice-column, and thus limiting its movement, and by its tendency to provide moisture to the clouds which furnished the glacier of that whole region with its fresh supply of snow, the neighboring waters of the Atlantic would seem to be an adequate cause for the phenomenon. At any rate, in the hills of Cape Cod, of Nantucket, of Martha's Vineyard, of the Elizabeth

Islands, and of the south shore of Rhode Island, and in those forming the backbone of Long Island, we have one of the most remarkable true terminal moraines anywhere to be found in the world.

Throughout their whole extent these terminal accumulations form a marked feature in the landscape, rising for a considerable portion of the distance from one hundred and fifty to three hundred feet above the general level of the country, and being dotted over with huge bowlders transported a greater or less distance from the north. Kettle-holes and the small lakelets which they inclose are also constant features in the landscape. Throughout this whole extent, also, the moraines are flanked on the south by extensive deposits of the "over-wash" gravel carried out by the water arising from the melting ice. The line of these moraines is, of course, at right angles to the direction of the ice-movement which terminated here.

It is a remarkable confirmation of the theory already presented in explanation of kettle-holes, that a study of those which mark the moraines of this region reveals a strong tendency in them to arrange themselves with their longer diameters parallel to the general trend of the moraine. Professor B. F. Koons* has taken the exact bearings of one hundred and six of these kettle-holes upon the island of Naushon and upon the mainland from Wood's Holl to Falmouth, and finds that the longer axis of eighty-two out of that number is approximately parallel to the direction of the moraine—that is, nearly at right angles to the direction of the ice-movement; and he is doubtless correct in his inference that "this is what we should expect if the kettle-holes marked the localities where fragments of ice were broken off from the face of the glacier and buried, wholly or in part, by the earth and stones borne down by the ice-sheet." By reference to the chapter upon the Muir Glacier, with the illustration there introduced, the reader may

* "American Journal of Science," vol. cxxvii, 1884, p. 260 *et seq.*; vol. cxxix, 1885, p. 480 *et seq.*

easily convince himself of the correctness of this suggestion. "Some of these kettle-holes," Professor Koons goes on to say, "are upon a truly grand scale; for example, one which contains several smaller within the large depression, and is like an immense amphitheatre with the hills rising upon every side of it. Its highest border is one hundred and fifty feet above the bottom and the outlet is forty feet above the small lake at its center; and on the south side, near its border, but upon still higher ground, a bowlder stands projected against the southern sky like a huge sentinel as the observer views it from the bottom of this immense pit." * As

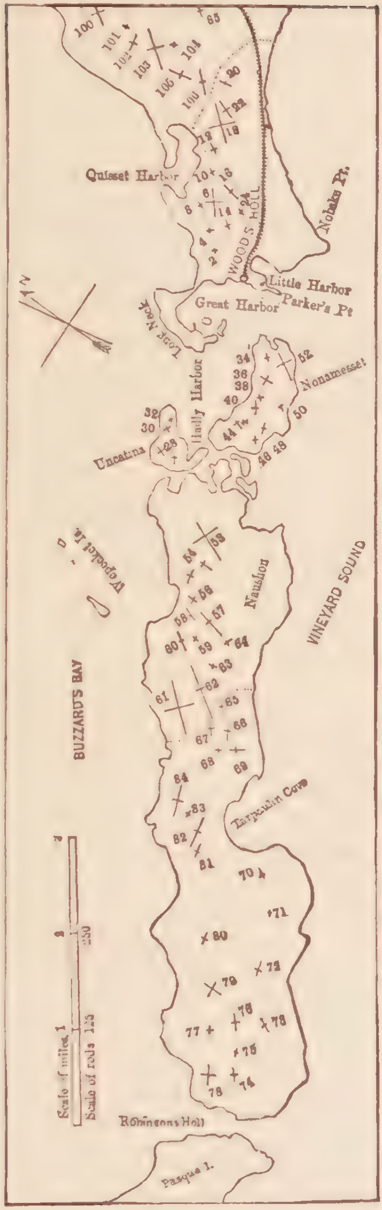

FIG. 64.—Map of kettle-holes on the northern part of the Elizabeth Islands, and in the vicinity of Wood's Holl, Massachusetts, by Professor B. F. Koons. The crosses show the direction of the longer and shorter axes. Nos. 66, 72, 76, 78, 82, 84, 86, 87, 89, 91, 92, 94, 95, 99, 100, 103, 105, 106, are upward of twenty-five rods in diameter; 95 and 103 are upward of fifty rods in diameter; several of them are about one hundred feet in depth.

* "American Journal of Science," vol. cxxvii, p. 262.

many as eight of those examined by Professor Koons were upward of eight hundred feet long and about half as wide; the rims from seventy-five to a hundred feet high.

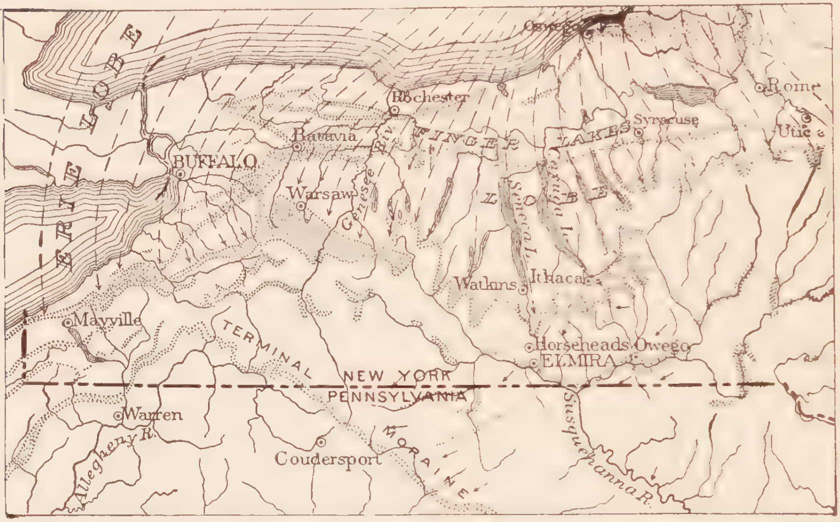

FIG. 65—Map of western New York, showing distribution of morainal deposits. (From U. S. Geological Survey.)

West of the Hudson Valley, as we have already seen, it is difficult to trace a well-defined and continuous moraine along the extreme glacial boundary. Such a moraine is pretty well made out across New Jersey and a portion of the distance between the Delaware and Susquehanna Rivers in Pennsylvania; but, beyond, the country is mountainous, and through a considerable portion of the way difficult of exploration. Through central New York, however, there are specially marked accumulations of glacial *débris* near the water-partings between the St. Lawrence and Mohawk Valleys and that of the Susquehanna. President Chamberlin is inclined to correlate the accumulations just south of the "Finger Lakes" of that region † with the interior moraine

† "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch," p. 353.

which we have described as running through Cape Cod, Elizabeth Islands, the southern portion of Rhode Island, and the northern part of Long Island, and also with those to be described more particularly hereafter as the Kettle Range, in Wisconsin. This interior line he would designate "the terminal moraine of the second Glacial epoch." But, in order to avoid the assumption of a distinct second Glacial epoch before conclusive proof is presented, the happy phrase of Professor Cook, of New Jersey, seems preferable, who would call the marked accumulations in the region to the north of the glacial limit "moraines of retrocession." Still, there is no great impropriety in calling them simply terminal moraines, since, wherever the ice-front paused for any length of time, a special accumulation of *débris* would take place, and would be terminal to the ice at that point.

West of the Alleghanies, President Chamberlin delineates this moraine as extending in a series of lobes pointing to the south across the States of Ohio and Indiana, making one grand loop whose axis is nearly parallel with that of Lake Erie, returning with its western arm into eastern Michigan, between Saginaw Bay and the southern end of Lake Huron. He discovers five minor loops in this moraine in the axes of the following river valleys: (1) the Grand and Mahoning; (2) the Sandusky and Scioto; (3) the Great Miami—all in Ohio; (4) the White, in Indiana; and (5) the Maumee and Wabash. But the accumulations called terminal in this region are by no means comparable in extent with those south of New England or west of Lake Michigan, and the system is made out with some difficulty.

In this portion of the territory there is another interior morainic belt of such interest that we pause to describe it more particularly. We refer to that of the Maumee Valley in Ohio, and can best describe it in the words of Mr. G. K. Gilbert, its original discoverer:

The Maumee River occupies the axis of the broad, shallow valley which it helps to drain. This valley has no strongly

marked limits. Eastward it is continuous with the trough of Lake Erie, and westward with the valley of the Wabash River. At the north, or more properly the northwest, its slopes merge, at a height of five hundred to six hundred feet (above Lake Erie), with those of the valley of Lake Michigan; and its southern slopes, reaching a height of four hundred to five hundred feet, pass into those of the Ohio valley. With these low sides and a width of 125 miles, all its inclinations are exceedingly gentle, and the title of plain can be applied to it with no less propriety than that of valley. North of the Maumee the general descent is to the southeast, and south of that river to the northeast. With slight exceptions, the smaller streams follow and indicate these slopes, but all the larger tributaries of the Maumee, including the St. Joseph, St. Mary's, and Auglaize Rivers, and Bean or Tiffin Creek, appear to be independent of them. The St. Joseph, for example, flows to the southwest through a country where every rivulet runs to the southeast. The entire region drained by it lies on its right bank, while from its left the drainage is toward Bean Creek, the divide between the two streams being everywhere within three or four miles of the St. Joseph. In like manner, the course of the St. Mary's is west and north, and, while from its left bank the streamlets flow northeast into it, from its right they flow northeast into the Auglaize. These hydrographical peculiarities are so singular and striking as to have excited some attention and curiosity before the region was visited. Upon examination, there was found a continuous ridge, following the eastern banks of these rivers, and evidently determining their courses. Running somewhat obliquely across the slopes of the country, it turned aside all the small streams, and united them to form the St. Joseph and St. Mary's. The height of this ridge is ordinarily from twenty-five to fifty feet, and its width at base from four to eight miles. Along the St. Joseph it is not distinguished from the adjacent country by its superficial characters. In common with that, it has a gently rolling surface, with a gravelly clay soil, supporting a heavy growth of varied timber. Farther south, where it forms the north bank of the St. Mary's River in Van Wert and Mercer counties, it is marked by such peculiarities as to divide it very sharply from the adjoining

plains, which are nearly level, with a soil of fine clay, and covered by a heavy growth of elm, beech, ash, maple, etc. The ridge, on the contrary, presents a confused series of conical hills, chiefly of clay, but showing some pebbles and small bowlders, and clothed by a forest-growth almost exclusively of oak. Probably the only essential point in this contrast is that of hill and plain, and out of this the others have grown. There is good reason to believe that the clay deposit (Erie clay) of the plain is continuous with that on the hills. Where its surface is level, it has retained its soluble salts and accumulated vegetable mold, so as to form a rich soil favorable to a varied vegetation; while from the steep hill-sides a great amount of soluble and fine material has been washed, so as to bring to the surface some of the pebbles everywhere imbedded in greater or less abundance, and the character of the vegetation has been determined by that of the soil.

I conceive that this ridge is the superficial representation of a terminal glacial moraine, that rests directly on the rock-bed, and is covered by a heavy sheet of Erie clay, a subsequent aqueous and iceberg deposit. Though this formation has an average depth along the upper St. Joseph of over one hundred feet, and on the upper St. Mary's of fifty feet, it has not sufficed to conceal a moraine of such magnitude, but has so far conformed to its contour as to leave it still visible on the face of the country—doubtless in comparatively faint relief, but still so bold as to exert a marked influence on the hydrography of the valley.*

When, a little later, we come to speak of glacial erosion, something more will be said confirmatory of this hypothetical moraine of Mr. Gilbert, and of the varying movements of ice in the Lake Erie Valley at different stages of the Glacial epoch. We shall then see abundant reason for supposing that there was, for a considerable length of time about the close of the period, an independent movement of ice in the direction of the longer axis of the lake, and that this

* "On the Surface Geology of the Maumee Valley," in the "Geological Survey of Ohio," vol. i, pp. 540–542.

Fig. 66.—Western face of the kettle moraine, near Eagle, Waukesha County, Wisconsin. (From photograph by President T. C. Chamberlin, United States Geological Survey.)

movement was directly toward the head of the Maumee River.

The general system of interior moraines upon which we were remarking is pretty well exhibited about the eastern shore of Lake Michigan, forming a grand loop around that lake, and connecting with two subordinate loops around the head of Grand Traverse Bay and Saginaw Bay. But it is not until reaching the country west of Lake Michigan, in Wisconsin, that these glacial accumulations become again a very prominent feature of the landscape. Here they constitute the so-called Kettle Range, which forms a loop pointing to the southwest in the line of the longer axis of Green Bay. President Chamberlin has shown * that the ice-movement to the southward through Green Bay was in a measure independent of that through Lake Michigan; so that the eastern arm of the Kettle Range might more properly be called a medial moraine, to which the Lake Michigan Glacier and the Green Bay Glacier both contributed their deposits. This eastern arm runs about half-way between Fond du Lac and Sheboygan, and thence a little west of south, through Washington and Waukesha counties, between Oconomowoc and Pewaukee, and through Eagle to Milton, between Janesville and Whitewater. Thence it swings northward, passing a few miles west of Madison, and, crossing an elbow of the Wisconsin River, incloses in its folds Devil's Lake, near Baraboo, and thence on northward into the wilderness of northern Wisconsin, a little beyond the latitude of St. Paul, where it turns westward and with some deflection reaches the St. Croix River at Hudson, a few miles above its junction with the Mississippi. From this point it trends southward past Minneapolis through southeastern Minnesota, inclosing in its folds Minnetonka and many other beautiful lakes in that portion of the State. From this point on, Mr. Upham has traced the moraine in an ox-bow-shaped extension, whose

* "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch," p. 315, *et seq.*

southern extremity is near Des Moines, Iowa, and whose western limb is the Coteau des Prairies of eastern Dakota.

The conclusions of Mr. Upham and President Chamberlin, concerning the movements of the ice over the region west of the lakes, are intensely interesting and seem amply warranted by the facts. It appears that in the northwest the ice advanced in four lines of motion pointing to a center a little below Dubuque, Iowa, though the columns did not all reach the point of their apparent destination: 1. One line of advance was down the depression of Green Bay, in Wisconsin. The moraine of this lobe constitutes what is called the Kettle Range of that State, and terminates a little west of Madison, on the eastern edge of the driftless region. 2. A second line of movement was down the valley of Kewanee Bay. This movement spent its force in northern Wisconsin, reaching the vicinity of Eau Claire. 3. The third movement was along the line of the main axis of the western end of Lake Superior, and extended across the Mississippi past Minneapolis, as far as Lake Minnetonka, and to a line running northwest from this point for a hundred miles or more. 4. The fourth movement was from the region of Lake Winnipeg in the Red River Valley toward the south and southeast, meeting and opposing the ice-current from Lake Superior, along a line from Stearns county, Minn., southeast by Lake Minnetonka to Crystal Lake in Dakota county. This is the movement which extended southward to the vicinity of Des Moines, Iowa, and whose western flank is the Coteau des Prairies.

The line northwestward from Minneapolis, where these last two movements met, was an interesting battle-ground of the glacial forces. First, the Lake Superior Glacier prevailed, and pushed over the ground to its extreme limit, even beyond the Mississippi. This boundary-line runs from Crystal Lake through Minnetonka, Wright, and Stearns counties, Minn. A little later, the Red River Glacier gained the ascendency, pushing the front of the Lake Superior Glacier back into Wisconsin, east of the Mississippi.

The reality of this battle of the glaciers, and of this alternate advance and retreat of the opposing forces, is shown by the succession of deposits. The lower part of the ground moraine is characterized by a reddish color, and by rock-fragments from the region of Lake Superior; while the upper portion, now upon the surface, is of a bluish color, containing bowlders and pebbles of limestone and of cretaceous shale, and other material brought from the northwest, showing that victory was first to the Lake Superior Glacier, but finally to that of the Red River.

The evidence of the junction of these two great ice-streams appears clearly enough upon the surface when sections of country a little distance apart are considered. This, Dr. G. M. Dawson had observed as early as 1875, when he wrote about it thus:

> A line drawn northeast and southwest, nearly parallel with the northwestern shore of Lake Superior, but lying a short distance back from it, and cutting the Northern Pacific Railway some miles west of Thomson, in this part of Minnesota, separates superficial deposits of different aspects. Northwest of this line the prevailing tint of the drift material is pale yellowish-gray, or drab; southeast of it, reddish tints are almost universal, and become specially prominent on the northern part of the line of the Lake Superior and Mississippi Railway, and continue to St. Paul. The junction of these two varieties of drift can not, of course, be exactly defined, but is interesting as an indication of the direction of transport of material in this region: the reddish matter being derived from the red rocks of the lake-shore.*

Some other interesting things concerning the deposits of this region can better be said when we come to treat of glacial dams and lakes, and of the cause of the Glacial period.

The surprising thing to a glacialist, upon a first visit to

* "Report on the Forty-ninth Parallel," p. 213. See also "The Fresh-Water Glacial Drift of the Northwestern States," p. 9, by Colonel Charles Whittlesey, who, it would seem, had noted the distinction as early as 1866.

southeastern Dakota, is the extensiveness of the apparently level areas where the till comes to the surface. This impression is heightened, probably, by the absence of forests, and would very likely be the same in portions of Ohio and Indiana were it not for the timber. James River Valley, in Dakota, is depressed in the center about five hundred feet below the edges, but it is, roughly speaking, seventy miles across, and therefore the slope does not strike the eye. So level is the country, that every special line of glacial accumulation is a prominent feature in the landscape, and the various halting-places of the ice in its retreat are readily discerned. Evidently, a lobe of ice for a long time filled the James River Valley, running parallel with that which occupies the upper Minnesota Valley, and extended southward into Iowa. The edges of these lobes thinned out along the north-and-south line which runs near the east margin of southern Dakota, and favored the accumulation of the morainic hills, to which we have already referred as the Coteau des Prairies. Professor Todd and others speak of this as a series of terminal moraines formed along the sides of the re-entrant angle, between the two lobes, whose apex penetrated to the vicinity of the Sisseton Agency. Perhaps, however, it would facilitate a proper understanding of the subject to speak of the Coteau des Prairies as a medial moraine, like that east of Green Bay, toward which the glacial *débris*, carried on the deeper portions of the ice of both the Minnesota River and James River lobes, gravitated in contrary directions. But, whatever the name, certain it is that, starting from the Sisseton Agency, different lines of glacial accumulations stretch southward at varying angles, the later accumulations forming the more obtuse angle. Coming up the valley of the James from Yankton, one crosses the oldest of these accumulations (the Altamont Moraine) in the neighborhood of the city itself, and the second (or Gary Moraine) in the neighborhood of Mitchell, sixty miles to the north, having run parallel with it, however, for about thirty miles. The third (or Antelope Moraine) is encountered near

Huron, about sixty miles north of Mitchell, and continues visible upon either side of the river about twenty miles distant, as far up as Aberdeen.

The western side of this lobe is characterized by corresponding lines of receding moraines, the outer of which is in the vicinity of the Missouri River and on its eastern side. Together, these form the Missouri coteau. Everywhere, in coming up from the river on the west to the plateau, which is in most places from four hundred to five hundred feet above the river, one encounters two or three bowlder-covered terraces, the highest of which are at an elevation of from three hundred to four hundred feet. The moraines rise to a considerable height above the general level, and, as upon the eastern side, are everywhere marked features of the landscape. The streams entering the Missouri from the east are all of them short, none being more than forty miles in length. These streams are in all cases bordered by broad and elevated local terraces, the edges of which, where they overlook the immediate trough of the stream, are crowded with granitic bowlders. In some cases, as Professor Todd has shown, these valleys terminate abruptly in the water-parting, as if being the continuation of glacial streams from the east, which had originated upon the ice-lobe while it filled the James Valley.

Professor Todd, to whom the exploration of this region was assigned, thus describes the Missouri coteau:

This moraine consists of loops, convex usually toward the west and south, but in rare cases toward the northwest, as will be seen. These loops connect at re-entrant angles pointing toward the northeast and east, which are usually sharp, and sometimes are extended into elongated ridges. The moraine varies in elevation with the region on which it rests. Its relative height is usually great at the head of the re-entrant angles or interlobular moraines. These frequently stand out like great promontories, rising from one hundred and fifty to four hundred feet above the plain around them. At the bottom of a loop the moraine is apt to be slight or wanting, if on


SKETCH MAP
OF THE
MISSOURI COTEAU
AND ITS
MORAINES.
BY J. E. TODD,
Asst. Geologist U. S. G. S.
Moraines 1, 2, 3 & 4.
Contours
Railroads
Limit of Drift
Shore of Lake Dakota
Devil's Lake
Bismarck
Jamestown
Fort Yates
Aberdeen
Redfield
Watertown
Huron
De Smet
Mitchell
Chamberlain
Pierre
Oahe
Yankton
Sims
THE GREAT REE VALLEY
BALD MTS.
REE HILLS
MANY BUTTES
LIMIT OF DRIFT
Missouri
James
River
Niobrara R
Big Cheyenne R
Moreau R.
Grand R
Cannon Ball R
Heart R
Beaver R.
Mouse R.
Red River of the North
Cheyenne R.
White R
Turtle Point
TURKEY RIDGE
LOESS
Wakpa

Fig 67.

lower land; the flow of water from the ice probably having carried away the *débris* as rapidly as it was pushed forward by the ice. On the other hand, in case the loop was pushed up an inclined plane, and the water did not find free escape, it (the loop) is well developed all around. The outer moraine in some places is very rough and stony; at other points it is a smooth, broad ridge, with few knobs, and covered with a deep, fertile soil.*

Dr. G. M. Dawson early discovered the significance of this great Missouri coteau in its extension north of the United States boundary-line, and thus describes it:

On approaching its base, which is always well defined at a distance, a gradual ascent is made, amounting, in a distance of twenty-five miles, to over 150 feet. The surface at the same time becomes more markedly undulating, as, on nearing Turtle Mountain from the east, till almost before one is aware of the change, the trail is winding among a confusion of abruptly rounded and tumultuous hills. They consist entirely of drift material; and many of them seem to be formed almost altogether of bowlders and gravel, the finer matter having been to a great extent washed down into the hollows and basin-like valleys without outlets with which this district abounds. The ridges and valleys have in general no very determined direction, but a slight tendency to arrangement in north-and-south lines was observable in some places.

The bowlders and gravel of the coteau are chiefly of Laurentian origin, with, however, a good deal of the usual white limestone and a slight admixture of the quartzite drift. The whole of the coteau belt is characterized by the absence of drainage valleys; and, in consequence, its pools and lakes are often charged with salts, of which sulphates of soda and magnesia are the most abundant. The saline lakes frequently dry up completely toward the end of the summer, and present wide expanses of white efflorescent crystals, which contrast in

* "Proceedings of the American Association for the Advancement of Science," vol. xxxiii, 1884, p. 383.

Fig. 68.—Map and section of part of the interior of North America, showing the glacial deposits described in the text. (G. W. Dawson.)

color with the crimson *Salicornia* with which they are often fringed.

Taking the difference of level between the last Tertiary rocks seen near the eastern base of the coteau and those first found on its western side, a distance of about seventy miles, we find a rise of six hundred feet. The slope of the surface of the underlying rock is, therefore, assuming it to be uniform, but little more than four feet per mile. On and against this gently inclined plane the immense drift deposits of the coteau hills are piled.

The average elevation of the coteau above the sea, near the forty-ninth parallel, is about 2,000 feet; and few of the hills rise more than one hundred feet above the general level.

Between the southwestern side of the coteau belt and the Tertiary plateau is a very interesting region with characters of its own. Wide and deep valleys with systems of tributary *coulées* have been cut in the soft rocks of the northern foot of the plateau, some of which have small streams still flowing in them fed by its drainage; but for the most part they are dry, or occupied by chains of small saline lakes which dry up early in the summer. Some large and deep saline lakes also exist which do not disappear even late in the autumn. They have a winding, river-like form, and fill steep-sided valleys. These great old valleys have now no outlet; they are evidently of preglacial age, and have formed a part of the former sculpture of the country. The heaping of the great mass of *débris* of the coteau against the foot of the Tertiary plateau has blocked them up and

FIG. 69.—The Missouri coteau, forming the edge of the Third Prairie. Long. 104° W. (From the northeast, distant about four miles.) (G. W. Dawson.)

prevented the waters finding their way northward as before; and, since glacial times, the rainfall of the district has never been sufficiently great, in proportion to the evaporation, to enable the streams to cut through the barrier thus formed. The existence of these old valleys, and the arrangement of the drift deposits with regard to them, throw important light on the former history of the plains.

Northward, the coteau ceases to be identified with the Tertiary plateau, and rests on a slope of cretaceous rocks. It can be followed by Palliser's and Hector's descriptions of the country to the elbow of the South Saskatchewan, and thence in a line nearly due north through the Eagle and Thickwood Hills; beyond the North Saskatchewan, however, it appears to become more broken and less definite. In Dr. Hector's description of certain great valleys without outlet in this northern region, I believe I can recognize there, too, the existence of old blocked-up river-courses similar to those just described.

South of the forty-ninth parallel the continuation of the belt of drift material can also be traced. It runs southeastward, characterizing the high ground between the tributaries of the Missouri and the Red River, which has already been noticed in connection with the water-shed of the continent; but, wanting the backing of the lignite Tertiary plateau, it appears to become more diffuse, and spread more widely over the country. That the drift deposits do not *form* the high ground of the water-shed, but are merely piled upon it, is evident, as cretaceous rocks are frequently seen in its neighborhood at no great depth. . . .

In the coteau, then, we have a natural feature of the first magnitude—a mass of glacial *débris* and traveled blocks with an average breadth of perhaps thirty to forty miles, and extending diagonally across the central region of the continent for a distance of about eight hundred miles.*

To one familiar with the literature of the subject, it would seem that Dr. Dawson's sagacity in thus early dis-

* "Quarterly Journal of the Geological Society," vol. xxxi (November, 1875), pp. 614–616. The facts are more fully stated in his governmental "Report on the Forty-ninth Parallel."

cerning the great significance of the Missouri coteau has not received from glacial writers all the recognition it fairly deserves. But here we have, as in so many other instances, fresh illustration of the fact that the minds of sagacious investigators run in the same channel. Noteworthy inventions and discoveries are not often due to the work of single individuals. From the references already given, it would appear that Dr. Dawson's surmise as to the significance of the Missouri coteau, President Chamberlin's theory as to the meaning of the Kettle Range, Professor Cook's delineation of the moraine across New Jersey, and Clarence King's interpretation of the glacial accumulations on the south shore of Massachusetts were, in the minds of the authors, nearly contemporaneous and of independent origin.

The subject of this chapter will not be complete without speaking of those later and more local moraines which were formed when the ice had withdrawn itself from the country in general, but still lingered everywhere in the mountains. Such moraines are numerous in all the valleys of the White Mountains. Professor Agassiz * describes no less than fifteen terminal moraines of small size crossing the valley of the Ammonoosuc, a short distance below Bethlehem. Similar moraines exist in the valley leading down the Saco near Bartlett, and in the White Mountain branches of the Androscoggin, as well as in the valleys leading to the vicinity of Center Harbor, on Lake Winnepesaukee. The principal local moraine of the Androscoggin is near the State line between Shelburne, N. H., and Gilead, Me. This has been described by Professor Stone and others.† Other interesting moraines described by Professor Stone in Maine are located at Readfield Village, and at Swan Island in the Kennebec Valley, and at Sabbattusville, Machias, and Waldoboro.

Among the innumerable instances of local moraines on

* "Geology of New Hampshire," vol. iii, pp. 236–238.

† "American Journal of Science," vol. cxxxiii, 1887, p. 379.

the Pacific slope, the following, described by Mr. I. C. Russell, may serve as specimens:

> If one proceeds up the cañon [of Leevining River, Mono county, California], he will cross five or six small terminal moraines which traverse from side to side the broad trench left by the ancient glacier. These are seldom more than fifteen or twenty feet high, and are separated by grassy meadows. The creek was formerly dammed by these moraines and forced to expand so as to form small lakes; but these have long since been drained by the cutting of channels through the obstructions.*

Other instances have been already mentioned in describing the glaciated boundary in Colorado, southern California, Oregon, and the State of Washington. Moraines of retrocession characterize almost every mountain valley which was occupied by ice during the Glacial period.

The distribution of till in North America has been the subject of an immense amount of investigation during the past few years, accounts of which will be found in the various scientific journals and State reports. Most prominent of all are those carried on by Mr. Frank Leverett, Professor Geo. H. Stone, and Dr. Warren Upham of the United States Geological Survey, and embodied in the monographs on the "Glacial Formations and Drainage Features of the Erie and Ohio Basins," "The Illinois Lobe," "The Michigan Glacial Deposits" (by Leverett); "The History of Glacial Lake Agassiz" (by Upham); and the "Glacial Deposits of Maine" (by Stone).

From these it appears that there are no less than twelve moraines traceable across Ohio between Cincinnati and Lake Erie, all belonging to the last, or so-called Wisconsin Episode; these follow very irregular lines, and are not always easy of recognition. Evidently they are moraines of recession, indi-

*"Quaternary History of Mono Valley, California," p. 334.

cating points where there was a marked pause in the retreat of the front, affording time for a considerable accumulation of material, and perhaps sometimes of a short advance. These well defined morainic deposits mark a movement from Labrador as a center, and over a considerable area overrode earlier deposits which had been laid down by the movement from the Keewatin center west of Hudson's Bay. The Wisconsin moraines are well developed across New Jersey and Pennsylvania down to the line surveyed by Professor Cook and by Lewis and Wright as marked on our map. West of this the glaciated area in Ohio and Indiana was covered with Wisconsin drift down close to the southern border; while in Illinois it reached well down towards the center of the state, and in Iowa projected in a well defined loop as far as Des Moines, and in the Dakotas extended to the Missouri River.

An earlier movement from the same center is denominated the Illinoisan. This projected beyond the Wisconsin deposits over nearly all the western portion of Illinois, and crossed the Mississippi River for a short distance in the neighborhood of Burlington, compelling the river to flow for a short period in a new channel that can be traced from Clinton to Lee County, Iowa. Jaspar conglomerate bowlders from north of Lake Huron are found, with more or less frequency, over the whole region covered by the Wisconsin and Illinoisan deposits lying west of Pennsylvania and southeast of a line connecting Des Moines, Iowa and Green Bay, Wisconsin.

Outside of the Illinoisan area there is in Iowa a still earlier pretty well defined series of deposits called the Iowan. Mr. Leverett, however, does not now feel like recognizing these as distinct from the other deposits. But there is a very well defined line some distance outside the Wisconsin deposits, running across the state from east to west and nearly through the middle, separating an area which is covered by loess and one which is bare of loess, the loess evidently having been derived from the ice of the northern portion as it was swept

off by the melting waters. But of this we will speak more particularly when treating of the loess.

Still outside of the Iowan and the Illinoisan deposits there is a vast area in Southern Iowa, Northern Missouri, and Eastern Nebraska and Kansas, which is covered with a still older till, denominated Kansan. This till is much more thoroughly oxidized than the other, and is spread more evenly over the surface with an entire absence of moraines. Still farther east (in Illinois, Indiana, Ohio, Pennsylvania, and New Jersey) there is also frequently found an attenuated border of glacial material which is correlated with the Kansan, from its having many of the same characteristics. It is more completely oxidized, more evenly spread over the area, and is devoid of moraines. It now seems clear that this Kansan till is the result of a movement of ice which preceded those which deposited the other sheets of till and, moving eastward covered a large part of the field which is now enveloped with Iowan, Illinoisan and Wisconsin deposits. The extent of this eastward movement is not generally appreciated. But Professor E. H. Williams found Lake Superior copper firmly imbedded in "Kansan till," forty feet below the surface, at East Warren, Pennsylvania, several hundred miles east of the source of supply.

A still earlier glacial deposit has been recognized by the geologists of Iowa at Afton near the southern line of the State, and hence called the Aftonian Episode. This is recognized both by its position underneath the Kansan till and by its excessive oxidization. But, owing to its position it does not offer itself to inspection in many places, and even where it is visible its true age is a matter of speculation.

The earliest of all drift sheets is thought to have been recognized by Dr. George M. Dawson in the Province of Alberta, east of the Rocky Mountains, in Southern Canada, while Professor Calvin has discovered what he thinks is a Sub-Aftonian till in Iowa, which may correspond to that described by Dr. Dawson.

The main evidence of the age of these deposits will come up for discussion when we consider the date of the glacial period in general and of its various episodes. (See chapter XX, pp. 580–592).

But it will be in place to give expression at this point to some cautions against premature judgments respecting the evidence. It is important to keep in mind (1) the fact that there is no valid objection to the supposition that geological changes proceed much more rapidly at some periods than at others. Indeed it is a fundamental doctrine of evolution that cumulative strains in the earth's crust may go on unnoticed for an indefinite period until the limit of resistance is reached, when there will be a rapid readjustment which may well deserve the name of catastrophe. Preglacial elevation proceeded all through the latter portion of the Tertiary Period until the snows of the Glacial Period produced the ice age, when the very weight of the ice facilitated the subsequent depression and the rapid return to the ocean of the water that had been locked up in the continental glaciers. In this accumulation of ice over the northern hemisphere and its subsequent return to the ocean there is brought to light a force of such incalculable power affecting the elevation and depression of the land that the effects are entirely abnormal to our present experience. We cannot reason back from the rate of present changes to that of the Glacial Period.

(2) Again, we are never at liberty to lose sight of the fact that a long period of disintegration of the rocks over the glaciated region preceded the ice age. The rocks over that region were then rotted to a great depth as they are now in the region south of the ice limit. This furnished an immense amount of oxidized material for the first grist of the glacial mill, and that was spread widely over the southern margin of the glaciated area.

CHAPTER X.

GLACIAL EROSION AND TRANSPORTATION.

The extent of glacial erosion is a hotly contested question. One class of writers has gone to the extreme of attributing almost all the erosion of the higher latitudes to glacial action,

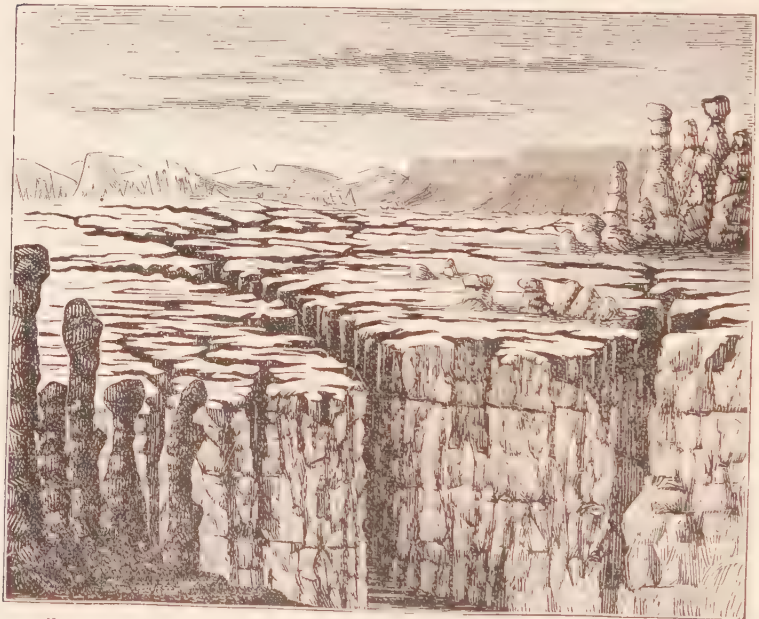

Fig. 70.—Cañon of the Colorado   Stream-erosion in a dry climate.   (Newberry.)

while another class has scarcely allowed any eroding power to glacial ice, in comparison with that of running water.

In considering the relative importance of these agencies,

PLATE VII.—Topography of deep loess, two miles south of margin of Iowan drift. Northwest of Iowa City, Iowa.

two elements enter into the problem: (1) the relative rate of action of the two forces, and (2) the relative length of time during which they have been in operation.

As to time, it is evident that those have a great advantage in the argument who exalt the eroding power of running water. However slowly the drops may wear away the stone, ample amends are made in the length of the periods through which the action has continued. From the earliest ages of geological history running water has been at work counteracting the effect of the forces which have elevated the continents. River-channels are, in fact, more constant than mountain-chains. Everywhere and at all times the accumu-

FIG. 71.—Embossed floor of an ancient glacier in the valley of the upper Arkansas River. (Hayden.)

lating waters on a continental area seek and find the lowest paths to the sea. The sand and gravel which these running streams push along over their beds act as the teeth of a saw upon the rising mountain-summits, so that everywhere in mountain-regions of great age we find deep, transverse val-

leys of erosion. Among the best-known examples in the country are those of the Mohawk and Hudson in New York; of the Delaware and Susquehanna in Pennsylvania; the Ohio and its tributaries on the western flanks of the Alleghanies; the Mississippi and all its western branches, together with the Colorado upon the eastern flanks of the Rocky Mountains; and the Columbia, the Fraser, and the Stickeen Rivers, which penetrate in chasms of great depth the rock-bound shore of the Pacific.

At the Delaware Water-Gap the river has sawn a vertical chasm more than a thousand feet deep directly across the hard strata of the Kittatinny Mountain. For fifty miles above Lock Haven, on the West Branch of the Susquehanna, the river occupies a narrow valley of erosion more than a thousand feet in depth. For nearly twelve hundred miles, as the water runs, the Ohio River, with its extension up the Alleghany, occupies a narrow, crooked valley, one mile or more in width and several hundred feet in depth, which it has worn through nearly parallel strata of lime and sandstone rock. The trough of the Mississippi from Cairo upward is similar to that of the Ohio, except that it is two or three times as broad. The cañons of the Colorado, of the Yellowstone, and of the Columbia, are of world wide renown. The Colorado has worn a channel with nearly perpendicular sides three hundred miles long and from three to six thousand feet deep.* Such are some of the well-recognized results produced by the long-continued mechanical action of running water.

But, aside from its mechanical action, water with the acids it contains is a most efficient chemical force, acting as a solvent upon various rocks. Every salt-spring and every spring of hard water in a limestone region is undermining the country from which it issues, and is engaged in dissolving the solid material and in transporting it in solution to lower levels. It is only a question of time when the chalk cliffs of

* "Elements of Geology," by Joseph Le Conte, pp. 15–17.

England and the extensive lime formations of the Appalachian region in America shall all be dissolved and carried in invisible solutions to the sea. The Mammoth Cave is but the remnant of larger, longer, and more numerous caverns which have honey-combed vast regions in Kentucky and in Tennessee. Many of the extensive valleys of that region are but the depressions formed by the falling in of the roofs of innumerable caverns.

The rate of chemical erosion on limestone rocks is not easy to estimate. The most elaborate attempt of which I am aware is that of Professor A. L. Ewing in the Nittany Valley, of Huntingdon county, Pa.*

This valley, which is known by different names, extends through a considerable portion of the Appalachian region. It consists of the remains of a great anticlinal fold, which, had it not been eroded away, would form an immense mountain-like plateau over 20,000 feet above its present height. As it is, the floor of the valley is composed of the upturned edges of the lower Silurian limestone, eroded through a thickness of 6,000 feet. The valley is flanked on either side by the overlying Medina sandstone, which forms monoclinical ridges from 600 to 1,000 feet above its floor.

From data carefully collected, Professor Ewing ascertains that the amount of solid matter annually carried out of the valley in chemical solution is equal to a layer of $\frac{1}{29173}$ of a metre in thickness. Hence, to lower the surface to the extent of one metre by this process would require 29,173 years—that is, it would take about 9,000 years to remove one foot from the surface.

It is safe to assume that had the rocks of this region been similar to those of the bordering mountains in their nature and power to resist dynamical agencies, we should have in place of Nittany Valley a mild anticlinal plateau somewhat above the

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* See "Proceedings of the American Association for the Advancement of Science," vol. xxxiii, 1884, p. 404. The paper was published in the "Second Geological Survey of Pennsylvania, T³," pp. 451–454.

mountains in elevation—say 1,000 feet above the present height of the valley.

The erosion in the valley, then, in excess of that along the mountains has been mainly chemical, and at least a thousand feet of limestone have been thus removed. A simple further deduction shows that, accordingly, Nittany Valley has been one million years in process of formation.

The limestone erosion could not begin before the latter stages of the Mesozoic era, possibly not before the Cenozoic era, as sufficient time must have elapsed subsequent to the Carboniferous age to erode all formations of the Palæozoic era above the Trenton limestone. One million years seems not inconsistent with other estimates of geological time.

In view of such facts the advocate of glacial erosion can not continue to maintain that ice is the chief agency in forming the contour of continental areas; but must grant that, by reason of the great length of time during which water has been about its work of corrosion and erosion, it is, without doubt, the most important instrument in diversifying the features of the earth's surface. Still, however short, by comparison, have been the periods of glacial action, no one can study a glacier or a glaciated region without being deeply impressed with the eroding and transporting power of moving ice. To get a full conception of its erosive power, one must either get beneath it, or be able to calculate the force of its movement from what he knows of the nature of ice. Neither of these plans is altogether satisfactory, but each of them is to some extent feasible.

From the nature of the elements at work it has quite generally been supposed that an advancing glacier would act like a plow or scraper, greatly disturbing and modifying the deposits over which it passed. But observation and a more careful consideration of the qualities of ice have materially modified these early impressions. From the fact that a stream of ice moves faster at the top than at the bottom, it follows that its action on underlying deposits is more like that of a drag than like that of a plow. The rocky frag-

ments frozen into the bottom of the ice are not held there by a perfectly firm and unyielding grasp. The same bowlder which plows a furrow in the rock beneath it, plows a longer furrow in the ice which is moving over it. This is finely illustrated by some observations of Professor Niles.

In a visit to the great Aletsch Glacier, in the summer of 1878, Professor Niles had an excellent opportunity to examine the under side of the ice of this glacier near its front. Here he observed numerous elongated ridges of rock over which the ice was flowing lengthwise, adjusting itself to all the corrugated surface. When the ice passed the lee end of the ridge it carried with it "the mold of the profile so perfectly that for more than twenty feet the blue arch presented a series of parallel furrows, like the flutings of a Doric column."

There was there at that time another highly interesting and instructive exhibition of glacial action. Within a few feet of the down-stream end of one of these elongated *roches moutonnées* and upon its crest, there was a bowlder fully three feet in diameter, which evidently had been slowly moving along this ridge for some distance, probably from its upper end. There were two sides of this block of stone which were not incased in ice, viz., the lower one resting upon the rock, and the one facing down the glacier. From the lower end of the ridge of rock I looked at the bowlder through a tunnel of pure, blue ice, which was continued as a deep furrow in the under surface of the glacier for fully thirty feet from its beginning. As this was produced by the ice moving over and beyond the bowlder, it was evident that the ice was moving more rapidly than the stone. I a. erward found other examples of the same kind, but none so favorably situated for a striking exhibition of this property of ice. It will be understood that these stones were sufficiently below the upper surface of the glacier to be removed from the effects of the ordinary changes of the temperature of the atmosphere. Although stones which are exposed to such changes may be frozen into the ice at the edges of the glacier, yet I believe these were so situated as to cor-

rectly represent the conditions and movements of this at still greater depths. If this is correct, and I believe it is, it follows that such fragments of rock are not rigidly held in fixed positions in the under surfaces of glaciers and carried irresistibly along at the same rate, but that the constantly melting ice actually flows over them, and that their motion is one of extreme slowness, even when compared with the motion of the glacier itself.*

In a visit to the glaciers of Norway in 1886, Professor J. W. Spencer found abundant confirmation of Professor Niles's inferences concerning the low eroding power of glaciers in certain conditions. He reports that the advancing Norwegian glaciers "do not conform to the surfaces over which they pass, but are apt to arch over from rock to rock and point to point, especially as they are descending the ice-falls."

Professor Spencer continues:

Beneath the glaciers of Fondal, Tunsbergdal, and Buardal, in the northern, north-central, and south-central snow-fields of Norway, as well as under other glaciers, I observed many stones inclosed in ice resting upon the rocks, to whose surfaces —sometimes flat, sometimes sloping steeply—they adhered by friction and by the pressure of the superincumbent weight. Although held in the ice on four sides with a force pushing downward, the viscosity of the ice, or the resistance of its molecules in disengaging themselves from each other in order to flow, was less than that of the friction between the loose stones and the rock; consequently, the ice flowed around and over the stones, leaving long grooves upon the under surfaces of the glacier.

An example of the ability of the ice to flow like a plastic body was shown in a cavern four hundred feet higher than the end of the glacier, where the temperature was 4° C., while that outside was 13° C. Upon the *débris* of the floor rested a rounded bowlder, whose longer diameter measured thirty inches. A tongue of ice, in size more than a cubic yard, was hanging

* "American Journal of Science," vol. cxvi, 1878, p. 366 *et seq.*

from the roof and pressing against the stone. In place of pushing the stone along or flowing around it, the lower layer of ice above the tongue had yielded, and was bent backward as easily and gracefully as if it had been a thin sheet of lead, instead of one of ice a foot thick.

The insufficiency of glaciers to act as great erosive agents is further shown at Fondalen, where a mass of ice thirty or forty feet thick abuts against a somewhat steep ridge of a rock ten feet or less in height. In place of a stone-shod glacier sliding up and over the barrier, the lower part of the ice appears stationary, or else is moving around the barrier, while the upper strata bend and flow over the lower layers of ice.*

The whole body of facts concerning a ground moraine speaks in like manner of the limited amount of disturbance, in certain conditions, which is produced by the ice as it moves over loose material. There can be little doubt that, for a breadth of a hundred miles or more on the border of the glacial limit in North America, the ice advanced *over* the loose material (which is variously called "bowlder-clay," "till," and "ground moraine") without greatly disturbing it as a body. Indeed, this great mass of firmly compacted, unassorted, and glaciated material would seem to have accumulated by degrees—the moving ice, dragging along under it successive strata of the grist which it had ground from the surface of the rocks far to the north, where its action had been more vigorous and long continued. For another striking illustration of the power of ice thus to move for a limited distance over loose material without disturbing it, one has but to refer to the description already given of the buried forest near the southwestern corner of the Muir Glacier, Alaska.† Here large trees in great numbers, which have been preserved for an indefinite period underneath the glacier, are now being uncovered, and appear standing upright

* See "Glacial Erosion in Norway and in High Latitudes," reprinted from "Proceedings of the Royal Society of Canada," 1887; extracted from "American Naturalist," vol. xxii, 1888, pp. 218, 221, 223.

† See p. 65.

with their branches intact upon them, and their roots imbedded in the soil in which they grew. A stratum of this soil even consists of moss and leaves and cones which originally formed a carpet over the forest floor. There can be no doubt that, after the accumulation of sand burying the forest, the glacier advanced for a great distance over it, attaining a thickness at that point of two or three thousand feet.

A little reflection will show that the advance of a glacier upon a new field is analogous to that of the breakers in the ocean over shallow bottoms, though the impressiveness of the scene is disguised to the physical senses by the slowness of the movement in the case of a glacier, and by the counteracting effect of the heat which limits the advance of the ice-front. Where the ice-movement is upon dry land, the front is ordinarily represented by a sloping field of ice covered with *débris* deposited from the melting surface near its terminus. For a long time investigators were puzzled by the fact that many bowlders are found some miles south of the line marking the limit of glacial scratches upon the surfaces of the rocks. But, in the light of the previous suggestions, it is easy to see that for some distance back from the southern margin there could have been no movement at all at the bottom of the ice, so that bowlders upon the surface might be transferred, as upon the summit of a breaker, from some distance back of the front to some distance beyond the farthest limit attained by the lower strata of moving ice. This narrow belt of glacial deposits bordering the limit indicated by other glacial signs constitutes what Professor Lewis and myself * agreed to call "the fringe" of the terminal moraine. West of the Alleghanies this fringe is, as already shown, so wide as to assume commanding importance, and everywhere deserves more attention than we at first gave it. †

This characteristic of the movement of glacial ice is illustrated by another phenomenon which has not been sufficiently

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* See "Second Geological Survey of Pennsylvania, Z," pp. 45, 206 *et seq.*

† See above, p. 149.

weighed. In most of the text-books the formation of icebergs is represented to be by the pushing out of the ice into the water until the depth is such as to overcome its specific gravity, and lift a mass of ice up bodily and float it away. An inference from imperfect data by Dr. Kane has doubtless done much to foster this idea.

Regarded upon a large scale, I am satisfied that the iceberg is not disengaged by *débâcle*, as I once supposed. So far from falling into the sea, broken by its weight from the parent-glacier, it rises from the sea. The process is at once gradual and comparatively quiet. The idea of icebergs being discharged, so universal among systematic writers and so recently admitted by myself, seems to me now at variance with the regulated and progressive action of Nature. Developed by such a process, the thousands of bergs which throng these seas should keep the air and water in perpetual commotion, one fearful succession of explosive detonations and propagated waves. But it is only the lesser masses falling into deep waters which could justify the popular opinion. The enormous masses of the great glacier are propelled, step by step and year by year, until, reaching water capable of supporting them, they are floated off, to be lost in the temperature of other regions.*

Doubtless some icebergs are thus formed. But any tourist to Alaska may now satisfy himself that the ordinary method of the formation of an iceberg is by the breaking off of masses from the top as that portion of the ice is pushed on in advance of the lower strata. Still, as the fractures would not always reach to the bottom of a deep inlet, masses thus left below the water would eventually rise to the surface in case the front of the ice were retreating, so as to remove the superincumbent weight from them.

Coming now to consider the direct action of glacial ice in the transportation of solid material, we speak first of that carried upon the surface. Apparently there is scarcely any

* "Arctic Explorations," vol. ii, p. 148.

limit to the size of the fragments of rock which can be transported upon the back of a glacier. Nor would there seem to be any definable limit to the distance through which these masses of rock can thus be carried, except as there is a limit to the movement of the ice itself. In walking out on the smooth surface of the eastern part of the Muir Glacier, it was not uncommon to encounter, miles away from any mountains, cubical blocks of stone as much as twenty feet in their several dimensions, which, with countless others of smaller size, united to form a medial moraine. Slowly but surely these great bowlders have been brought to their present position, and slowly but as surely they are moving on to the front of the glacier, where, in due time, they will be deposited in the terminal moraine.

FIG. 72.—Vessel Rock, a glacial bowlder in Gilsum, N. H. (C. H. Hitchcock.)

The summary of facts published by President Hitchcock many years ago may fitly serve as an introduction to the more detailed account to follow. In this, after remarking upon the great size of single bowlders, he illustrates the remark by the following examples:

The block called Pierre à Bot, near Neufchâtel, contains 40,000 cubic feet. It has been transported from near Martigny, more than sixty miles, across the great valley of Switz-

erland. Professor Forbes describes another bowlder in the Alps, one hundred feet long and forty to fifty feet high ; also another, sixty-two feet in diameter, containing 244,000 cubic feet. In this country bowlders occur of equal dimensions. Thus, on Cape Ann and its vicinity, I have not unfrequently met with blocks of syenite not less than thirty feet in diameter ; and in the southeast part of Bradford (Mass.) I noticed one thirty feet square, which contains 27,000 cubic feet, and weighs not less than 2,310 tons. In the west part of Sandwich, on Cape Cod, I have seen many bowlders of granitic gneiss twenty feet in diameter, which contain 8,000 cubic feet, and weigh as much as 680 tons. Two sandstone bowlders of the same size lie a few rods distant from the meeting-house in Norton. A granite bowlder of equal dimensions lies about half a mile southeast of the meeting-house in Warwick ; and one of similar dimensions lies on the western slope of Hoosac Mountain, in the northeast part of Adams, at least one thousand feet above the valley over which it must have been transported. One of granite lies at the foot of the cliffs at Gay Head, on Martha's Vineyard, which is ninety feet in circumference, and weighs 1,447 tons. In Winchester, N. H., I recently met with a block of granite eighty-six feet in circumference. It is near the road leading to Richmond. I noticed another in Antrim, in that State, one hundred and fifty feet in horizontal circumference. Finally, at Fall River was a bowlder of conglomerate which originally weighed 5,400 tons, or 10,800,000 pounds.*

A well-known bowlder in eastern Massachusetts, situated on a precipitous cliff in the southern part of the town of Peabody, goes by the name of Ship Rock. This is a granite, and measures forty-five feet in length by twenty-two in height, and twenty-five in width. Its estimated weight is 1,100 tons, and it is surrounded by many loose fragments weighing from fifty to seventy-five tons each. This rock has been purchased by the Essex Institute of Salem, and is carefully preserved from destruction.†

* "Elementary Geology," pp. 242, 243.

† See "Journal of Essex County Natural History Society," p. 120.

In Essex County, Mass., numerous bowlders are traced to the White Mountain region more than one hundred miles distant. Plymouth Rock is a bowlder which accomplished its pilgrimage long before the voyage of the *Mayflower*. The backbone of Long Island largely consists of morainic material torn from the rocky hills of Rhode Island, Connecticut, and Massachusetts. The "Judge's Cave" on West Rock in New Haven, 365 feet above the sea, is a bowlder weighing a thousand tons.

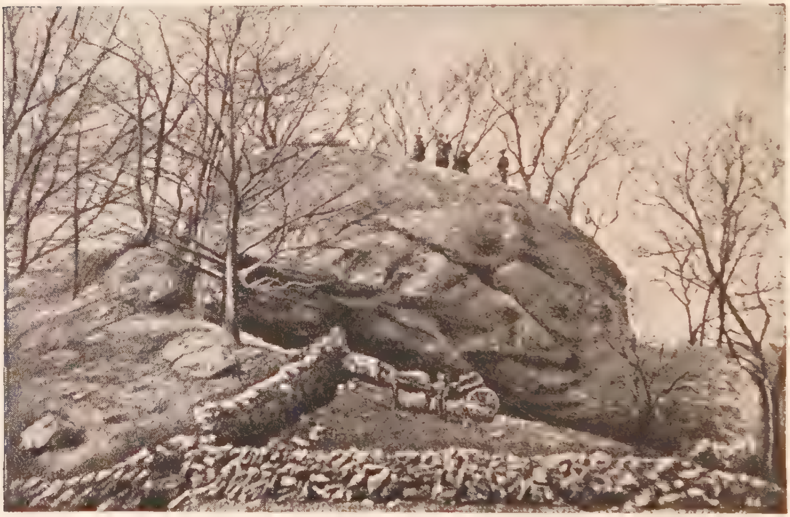

FIG. 73—Mohegan Rock.

The largest bowlder yet described in New England is Mohegan Rock, in the town of Montville, New London County, Conn. Its dimensions, as reported to me by Mr. David A. Wells, are as follows: Length of eastern side, 54 feet; southern side, 70; western side, 56; northern, 58; maximum height at least 60 feet. The weight has been estimated at 10,000 tons.

Professor Crosby, however, says that a bowlder in Madison, N. H., is still larger than this. Its dimensions are 30 x 40 x 75 which would give 96,000 cubic feet and an estimated weight

of 8,000 tons. But both these must give place to one mentioned by Professor Edward Orton at Oregonia in Warren County, Ohio, where a mass of Clinton limestone covering three-quarters of an acre, and twenty feet in thickness, has been moved by ice several miles and left with glacial deposits both above and below it. These, however, are small compared with a mass of chalk described by Professor Holst near Malmo in southern Sweden which is three miles long, one thousand feet wide and from one hundred to two hundred feet in thickness, and which has been transported an indefinite distance by glacial ice and left on the surface of ordinary deposits of till. This mass is extensively quarried for commerical purposes. The quarries show that the chalk, especially in its upper portions is much disturbed, being broken into small fragments. Even the flint nodules are generally cracked, but the mass as a whole is well defined. A similar transported mass of chalk is reported from the eastern shore of England upon which a village had unwittingly been built.

The train of bowlders in Richmond, Mass., near the summit of the Berkshire Hills, was long ago described by President Hitchcock and Sir Charles Lyell, and more recently and accurately by Mr. E. R. Benton.‡ So much has been written about this train of bowlders, that it is worth while to give the results of this later investigation. The locality is in the towns of Lebanon, N. Y., and Richmond, Lenox, and Stockbridge, Mass., upon the western side of the Berkshire Hills. The trend of the rocky strata here is nearly northeast by southwest, and the elevation of summits of the ridges about sixteen hundred feet above tide, the valleys being about six hundred feet lower. Beginning on the Canaan and Lebanon ridge in New York, there is a line of peculiar bowl-

* "Geology of New York," Part IV, p. 165, *et seq.*

† "American Journal of Science," vol. cxxvi, 1883, p. 347.

‡ Lyell's "Antiquity of Man," pp. 355–362; "Bulletin of Museum of Comparative Zoology at Harvard College," Cambridge, Mass., vol. v, No. III, p. 41, with map.

ders about four hundred feet wide, running continuously for nine miles southeast. These bowlders are composed of a chloritic schist, whose only outcrop is at Fry's Hill, on the summit of the Lebanon range. West of the ridge there are none of these bowlders, but east of the knob the train is continuous. Near the knob the size of the bowlders is larger than at a distance from it. Indeed, the size gradually diminishes as the distance increases. The bowlders are distributed equally over the valleys intervening and over the flanks and summits of the ridges crossed. Besides the main continuous train of bowlders there are three others more or less continuous for a part of the way, and originating near the same knob. The diameter of the bowlders varies from thirty feet near their origin, to an average of two feet in Stockbridge, nine miles away. In the vicinity are other bowlders from a ledge whose outcrop was from four hundred to eight hundred feet lower than the hills upon which they are now resting.

Sir Charles Lyell's explanation of these remarkable trains of bowlders was that they were deposited when the region was depressed, so that oceanic currents carried icebergs over the summits of the intervening range, dropping their burdens along on the way. But it is surprising that the burdens of the icebergs should have been deposited so regularly, and still more surprising that icebergs should have raised bowlders and deposited them on surfaces eight hundred feet higher than the ledges from which they were torn. This is one of those numerous cases where the glacial hypothesis easily explains all the facts, and where it is difficult to see how any other hypothesis can do so.

The only really peculiar thing about these celebrated trains of bowlders is that in their case the peak from which they are derived is isolated so that their origin can be readily traced. The prevailing rocks of this region are of such a nature that large bowlders could not readily be formed from them, whereas over most of the glaciated region the bowlders are so abundant and from such a variety of localities

that it is not easy to single out a particular train. Careful attention, however, will doubtless resolve the whole mass of till into confluent trains of bowlders and more finely comminuted material.

In New Jersey, according to Professor Cook, the bowlders are readily traced all along the morainic margin as belonging to well-known outcrops of trap, blue limestone, and crystalline rocks to the northwest. Near Drakestown, in Morris county, there is a mass of blue limestone which had been worked for years as a quarry without suspecting that it was but a bowlder. "As exposed it measures thirty-six by thirty feet, and the quarrying has gone twenty feet in depth. Its vertical diameter is unknown. Around it are many gneissic bowlders and other drift materials." * This mass is about one thousand feet above the sea-level, and its native place must have been some miles to the northwest.

In Pennsylvania the distance from which the glacial material near the border of the glaciated region has been transported becomes at once more evident, because of its unlikeness to the local rocks. West of the Kittatinny Mountain, there are no crystalline rocks within the State. Nor are there any to the north nearer than the Adirondacks in New York, or the highlands in Canada. Yet granitic, gneissoid, and hornblendic bowlders abound all along the glaciated border, and are an important means of determining the glacial limit. In the valley between Kittatinny and Pocono Mountains, in Monroe county, and on the summit of the Pocono plateau, 2,000 feet above the sea, granitic bowlders from one to three feet in diameter are abundant, though mingled with great piles of local fragments. The granite must have been transported a distance of 250 miles at least, and carried over the summits of the Alleghanies, intervening toward the northwest, and across the valley of the Mohawk in New York. The northern tributaries of the West Branch of the Susquehanna, likewise, bring down into that stream

* New Jersey Report for 1880.

numerous granitic pebbles, showing that glacial deposits in Lycoming county contain material from the far north which has been carried bodily over the summit of the Alleghanies. On proceeding west, the granitic outcrops from which the material could come, gradually recede to the north, thus increasing the distance between such bowlders and their nearest known source. From Salamanca, N. Y., southwestward to Cincinnati the whole country is literally covered, down to the glacial limit, with granitic, gneissoid, and hornblendic bowlders. Near Salamanca such bowlders abound at elevations not far from 1,900 feet above tide, and 700 feet above the Alleghany River. In Beaver county they are numerous on the hills down to within six or seven miles of the Ohio River, and several hundred feet above it.

The following are some of the more specific facts drawn from my own notes: In Columbiana county, Ohio, a granitic bowlder was found measuring thirteen by eleven feet, and eight feet out of the ground. Others near by were noted, measuring eight and five feet in diameter. In the same vicinity the till contains finely striated fragments of local sandstone, showing direct glacial action on the local rocks. In Holmes county, also, finely polished and striated pebbles of corniferous limestone occur, mingled with fragments of granite in the till. These must have been brought from the other side of the water-shed, in the vicinity of Lake Erie, 100 miles distant. Near Lancaster, in Fairfield county, there is a granitic bowlder measuring eighteen feet by eleven, and six feet out of the ground. In Ross county, near Adelphi, Chillicothe, and Bainbridge, numerous granitic bowlders were found on the hills from 400 to 600 feet above the valleys, and about 1,200 feet above tide. A hornblendic bowlder five by three by two feet was noted 550 feet above Bainbridge. In Brown, Clermont, and Hamilton counties large granitic bowlders abound on the hills down to the very northern edge of the trough of the Ohio. Here, also, are to be found numerous bowlders of jasper conglomerate from the region north of Lake Huron or near the lower end of Lake Superior. The

variegated pebbles of red jasper and of darker quartzites are a striking feature in the rocks of that northern region. The bowlders of this material found in the vicinity must have been transported nearly 600 miles. Several bowlders of this description were found in Boone county, Ky., a number of miles south of the Ohio River and between 500 and 600 feet above it. Bowlders of this jasper conglomerate are very abundant in Michigan, are not infrequent in northern Ohio, and occur in various localities in southern Indiana—one being observed near Nashville, Brown county, Ind., near the highest land in the State (about 1,100 feet). Granitic and hornblendic bowlders are very abundant, also, as far south as Carbondale, Jackson county, Ill., below latitude 38°. The surface rocks are here distinctly striated, and the transportation must have been independent of any conceivable current of water. The distance from this point to the parent ledges to the north can not be less than 600 miles.

All over northern Missouri, the whole of Iowa, and eastern Dakota bowlders of large size are of frequent occurrence. In some places they completely cover the ground, especially in the lines of the great moraines. Even west of the Missouri, for thirty miles beyond Fort Yates, granitic bowlders are so abundant as to be prominent features in the landscape. Farther north in the same Territory and in Montana they are reported as sometimes so thick that a person can walk for long distances upon them without touching the ground.

As has been already remarked, the glacial movement was everywhere at right angles to the glacial boundary. We should expect, therefore, to find that the bowlders along the western border of the glaciated area beyond the Missouri River had been transported from the northeast, and such is undoubtedly the fact. In the recent excursion (in 1888) through northern Nebraska and central Dakota, already referred to,* I had abundant occasion to see evidences of this transportation. On the hills in Nebraska, from 500 to 600

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* See above, p. 174.

feet above the Missouri River, extending in a southwest direction from Yankton, Dakota, to the glacial border, a distance of about forty miles, transported bowlders of considerable size are abundant, and among them are numerous specimens of the so-called Sioux Falls quartzite, whose nearest outcrop is about forty miles to the northeast.

All along upon the eastern side of the river in Dakota the glacial accumulations are on an enormous scale, and the transported bowlders without number; and on crossing the river at Fort Yates, about fifty miles south of Bismarck, granitic bowlders, in numerous instances from three to five feet in diameter, are found resting continuously over a belt of the highlands from 500 to 600 feet above the river, and extending about forty miles to the west, where they suddenly cease. There is granite in the Black Hills, 200 miles to the west, and from that source some pebbles have been brought down the Cheyenne River, which rises in that region. But with this exception, there are no granitic bowlders over the area between the Black Hills and this glacial border just mentioned. The source, therefore, of these bowlders on the west side of the Missouri River, extending from Bismarck to the Nebraska line, must lie somewhere to the northeast. Many of them might well enough have come from the vicinity of Lake Superior, a distance of 400 or 500 miles, though possibly some of them originated in more limited outcrops of granite in northern Minnesota.

In British America, the transportation was outward from the Laurentian axis in every direction. From this axis bowlders in immense quantities were carried from 600 to 700 miles westward and left on the flanks of the Rocky Mountains, from 2,000 to 3,000 feet above their source.

In Dr. George M. Dawson's report upon the extension of the Missouri coteau into the central region of North America, he estimated that nearly ninety-eight per cent of this great accumulation between the Missouri and Saskatchewan Rivers was from the Laurentian axis, some hundreds of miles to the east; and that, upon the fringe beyond the coteau,

where there is a mingling of material brought down from the Rocky Mountains, there is still for some distance as much as forty-eight per cent of Laurentian material.

Still farther north Dr. Dawson reports a movement of bowlders toward the north in the head-waters of the Yukon River, and in the northern portion of the continent east of Mackenzie River.

For the arctic coast of the continent and the islands of the archipelago off it there is a considerable volume of evidence to show that the main direction of movement of erratics was *northward*. The most striking facts are those derived from Professor S. Haughton's appendix to McClintock's "Voyage," where the occurrence is described of bowlders and pebbles from North Somerset, at localities 100 and 135 miles northeastward and northwestward from their supposed points of origin. Professor Haughton also states that the east side of King William's Land is strewn with bowlders of gneiss like that of Montreal Island, to the southward, and points out the general northward ice-movement thus indicated, referring the carriage of the bowlders to floating ice of the Glacial period.

The copper said to be picked up in large masses by the Eskimo, near Princes Royal Island, in Prince of Wales Strait, as well as on Prince of Wales Island,* has likewise, in all probability, been derived from the copper-bearing rocks of the Coppermine River region to the south, as this metal can scarcely be supposed to occur in place in the region of horizontal limestone where it is found.

Dr. A. Armstrong, surgeon and naturalist to the Investigator, notes the occurrence of granitic and other crystalline rocks not only on the south shore of Baring Land, but also on the hills at some distance from the shore. These, from what is now known of the region, must be supposed to have come from the continental land to the southward.

Dr. Bessells, again, remarks on the abundance of bowlders on the shore of Smith Sound in latitude 81° 30′, which are manifestly derived from known localities on the Greenland

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* De Rance, in "Nature," vol. xi, p. 492.

coast much farther southward, and adds, "Drawing a conclusion from such observations, it becomes evident that the main line of the drift, indicating the direction of its motion, runs from south to north."*

It may further be mentioned that Dr. R. Bell, of the Canadian Geological Survey, has found evidence of a northward or northeastward movement of glacier-ice in the northern part of Hudson Bay, with distinct indications of eastward glaciation in Hudson Strait.† For the northern part of the great Mackenzie Valley we are as yet without any very definite information, but Sir J. Richardson notes that Laurentian bowlders are scattered westward over the nearly horizontal limestones of the district.

Taken in conjunction with the facts for the more southern portion of the continent, already pretty well known, the observations here outlined would appear to indicate a general movement of ice outward, in all directions, from the great Laurentian axis or plateau which extends from Labrador round the southern extremity of Hudson Bay to the Arctic Sea; while a second, smaller, though still very important region of dispersion—the Cordilleran glacier-mass—occupied the Rocky Mountain region on the west, with the northern and southern limits before approximately stated.‡

Some facts already mentioned # have prepared the way for the discussion of that most puzzling and interesting problem of the upward transportation of earthy material in moving ice. The evidence upon this point is too abundant to be ignored. Professor Charles H. Hitchcock reports finding near the very summit of Mount Washington many small bowlders which must have been elevated a considerable portion of its entire height. One of these bowlders, weighing ninety pounds, is now deposited in the museum of Dartmouth College; and

* "Nature," vol. ix.

† "Annual Report of the Geological Survey," Canada, 1885, p. 14, D. D; and "Report of Progress," 1882-'84, p. 36, D. D.

‡ See "Glaciation of British Columbia," "Geological Magazine," August, 1888, pp. 348, 349.

See above, pp. 197, 240

another, of equal weight, may be found in the museum of the Boston Society of Natural History.* Professor Hitchcock writes me that while none of the very large bowlders in New Hampshire have been lifted up very much, it is safe to say that every New England mountain has bowlders on its summit that have been brought there by the ice from at least as great a distance as from its immediate base.

Describing a cut in till, forty feet deep, near the village of Queechee, Vt., on the Connecticut River, Professor Hitchcock says it is full of small-sized glaciated stones, cemented together by thick bowlder clay. Every stone is striated. There are great numbers of the Burlington (Vt.) red sandstone, "which must have traveled from over the Green Mountains, over sixty miles, and have been raised over an acclivity of 3,000 feet altitude." †

Professor A. S. Packard, Jr., reports ‡ that, at the height of about 4,000 feet above the sea, on Mount Katahdin, Me., "is a large mass of glacial moraine matter which has escaped denudation, and this incloses frequent rounded and polished bowlders of fossils of the same species of Silurian shells, and of the same silicious slates, as are found *in situ* a few miles northwest, on Lakes Webster and Telos. . . . The parent beds are but about twelve miles distant," and, according to Mr. Upham, must be 3,000 feet lower.

One of the clearest instances of the elevation of bowlders in the ice is the one already alluded to, # in the vicinity of the Delaware Water-Gap, on the summit of Kittatinny Mountain. This summit consists of Medina sandstone, and is about 1,500 feet above tide. Yet Professor Lewis found numerous bowlders of Helderberg limestone upon it, which he thinks must have come from Godfrey's Ridge, in Cherry Valley, only a few miles to the north, and 1,200 feet lower.

* For particulars concerning these bowlders, see Hitchcock, "New Hampshire Geological Report," vol. iii, pp. 204, 207, 272.

† "New Hampshire Geological Report," vol. iii, p. 262.

‡ "Memoirs of the Boston Society of Natural History," vol. i, p. 239.

See cut above, p. 196.

Professor Lesley adds his testimony that in all northeastern Pennsylvania there is no other source of these bowlders but the one line of outcrop mentioned by Professor Lewis; but, as it extends a hundred miles in a northeasterly direction, he is not sure that the particular locality from which these Helderberg bowlders came can be determined. Still, he is certain that every limestone bowlder in northern New Jersey and eastern Pennsylvania has come from some point along this line of outcrop. Nowhere, however, does the Helderberg limestone rise to an elevation of more than 1,000 feet above tide, while some of these bowlders are 1,500 feet above tide. Remarking upon this, Professor Lesley says:

The only problem of prime difficulty is, how the ice managed to lift the fragments from the outcrop in the valley to the crest of the Kittatinny Mountain—a problem which is repeatedly presented for our solution at various points where the terminal moraine crosses our mountain-ridges, and where blocks from a valley to the north are left perched on a mountain-top to the south. And the problem is not confined to the line of the moraine, but repeats itself at points many miles back of the moraine. Twenty years ago I found Catskill red sandstone fragments which had been carried up the north flank of the Towanda Mountain, in Bradford county, and been left on the edge of a swamp upon its flat summit of coal-measure sandstone; and there is no Catskill country to the north of a higher elevation from which the ice could have brought them with a descending gradient.

Professor James Hall informs me that fragments from the Mohawk Valley have been carried up over the Helderberg Mountain to the south of it, precisely as the Rondout-Walkill bowlders have been carried over the Kittatinny Mountain.

So, judging by the southeast striæ, the gneiss and granite bowlders of western Pennsylvania must have been carried up from the level of Lake Erie (570 feet above tide) to elevations of 1,500 feet, along the line of the terminal moraine, 1,700 feet above tide at Lake Chautauqua, and even 2,150 feet above tide

in Little Valley, Cattaraugus county, N. Y.; unless we suppose that all the Canadian bowlders were borne upon the *surface* of the ice, which is clearly impossible.

Bowlders of Alpine glaciers seem always to *descend* to their final resting-place, but we have innumerable proofs that the American ice-sheet managed, in some way, to carry bowlders from valleys up to mountain-tops, although the amount of elevation in many cases, if not in all cases, may be much less than we are inclined, on a first inspection of the facts, to take for granted.

In the case of the Helderberg limestone bowlders mentioned, found by Mr. Lewis on the crest of the Kittatinny Mountain, it is not necessary to suppose that it came from Godfrey's Ridge, only three miles distant (north) in the valley below, 1,000 feet beneath its present position. Indeed, the direction of the scratches on the mountain-side make such a supposition incredible. It is plain that it must have traveled down the valley of the Delaware, and may have come from the continuation of the range in the State of New York. The elevation of the surface gradually increases going east. The rise in the bed of the river for the first thirty-five miles, from the Delaware Water-Gap to Port Jervis, is about 200 feet. The rise from Port Jervis to the Rondout-Walkill divide, twenty miles, is 80 feet more. There the crest of the Helderberg Ridge must be nearly 1,000 feet above tide. The crest of the Kittatinny Mountain where the block lies is about 1,500 feet above tide. Therefore, if the block came these sixty-five miles, it has been carried up only 500 feet above its original situation.

Still, it remains a problem by what sort of internal movement a stone held in the ice can *ascend*, however gentle may be the gradient upward. That internal movements take place in all glaciers, is made visible to the spectator by their spoon-shaped stratification, and by the different rates at which their upper, lower, middle, and lateral parts move along, as well as by the fact that they press forward over rock-barriers. But so general a statement has no scientific value when evoked to explain the actual translation of a bowlder up a mountain-slope. In fact, our knowledge of how such an operation was

performed is as vague as possible, and demands the attention of hydraulic engineers.*

Elsewhere † I have briefly considered the way in which this upward movement of bowlders imbedded in the glacial current might be produced. The subject is of so much interest and importance that it will be well to recur to it here.

As a result of the differential motion in a glacier in which each higher stratum of ice is moving slightly faster than that which is immediately below it, it follows that the inclosed bowlders are subjected to a differential strain, in which the upper portions are impelled forward with greater rapidity than the lower portions. The result of this differential strain upon the upper and lower portions of the bowlder, combined with the friction and viscosity of the ice, must produce a movement slightly upward as well as forward. The bowlder, being inelastic, or at any rate less elastic than the ice in which it is imbedded, must move as one mass, while each particle of ice moves in independence of all the others. Now, the portion of ice lying immediately in front of a bowlder, being protected from the differential pressure of the ice behind by the interference of the inelastic foreign object, offers more resistance in that direction than is presented along a line leading diagonally upward across the lines of greater movement above. In other words, the frictional pressure of the moving ice upon the upper portion of a bowlder is greater than that on its lower portions, and the greatest of all resistance is immediately in front. The line of least resistance is consequently always in a direction slightly upward. If, for example, the movement of the ice at the upper surface of a bowlder be represented by 100, and that at the lower portion of the bowlder by 99, then one one-hundredth of the force might be supposed to be expended in producing a diagonal upward movement. Thus we can conceive that fragments of rock were picked up from beneath the glacier,

* See "Second Geological Survey of Pennsylvania, Z," p. xxiii *et seq.*

† "Glacial Boundary in Ohio, Indiana, and Kentucky," p. 31.

and that, after moving a sufficient distance, they appeared upon its surface; and we can easily believe that many bowlders have thus been repeatedly transferred from beneath the ice to its surface, and thence projected by the more rapid superficial motion to the front to be reincorporated into the lower strata of the mass, and re-elevated to the surface again.

Upon this subject Professor Lesley offers the following ingenious suggestions:

When two equal solid bodies descending opposite slopes meet, they arrest and support each other.

Imagine myriads of cannon-balls rolled from both sides to meet in the middle of a symmetrical valley. Those arriving first would remain ever afterward the lowest stratum; those which followed would arrange themselves in higher and higher layers until the valley was full or the supply exhausted. No shifting of places would take place after each had found its lowest place.

But suppose opposite descending quantities of pitch, or moist clay, through which cannon-balls were scattered, to meet along the middle line of a valley; the two advancing fronts would mash against each other, and thicken upward, the included cannon-balls rising vertically in the thickening mass, the thickening being in proportion to the height and weight and rigidity of the masses of clay pressing from the side slopes upon the middle line which had come to rest.

By substituting plastic ice for moist clay, and rock-bowlders for cannon-balls, we get an idea of how the American ice-sheet may have carried up (diagonally) the masses which it tore from low-lying outcrops to higher levels, and even over mountain-crests. . . .

A terminal moraine is often described as if it were merely the tumbled-off accumulation of the medial and lateral moraines which cover the surface and sides of a glacier. But the fact is, that a glacier is like a plum-pudding—full of scattered sand and stones from top to bottom and from side to side, all of which are delivered at its front end down the valley. The surface exhibition is made much stronger than it would otherwise be by the perpetual melting of the upper surface and sides

of the glacier. This brings the plums in the pudding to the surface, and mixes them with the medial moraine blocks which

FIG. 74.—Glaciated pebble from southern Indiana. Natural size. This was one of the graving tools of the glacier. The striæ are parallel with the longer axis.

have ridden down from the forks of the valley. A constant concentration of the *débris* of the whole glacier thus goes on at its surface in spite of the occasional loss of some of the stuff by dropping into crevasses, the blocks thus temporarily lost rejoining their fellows at the surface, if the glacier be long

enough, lower down the valley, or issuing midway of its front end in the mass of the terminal moraine.*

It is urged, both against the foregoing statement of facts and their theoretical explanation, that observations in Green-

FIG. 75.—Reverse side of the same pebble.

land are irreconcilable with them. For it seems to be admitted that the surface of the great ice-cap of Greenland is

* "Second Geological Survey of Pennsylvania, Z," p. xxv *et seq.*

free from bowlders, except in the lines of movement extending from the *nunataks*. A sufficient reply to this objection is to say that a country so long subject to glacial movements as Greenland has been must already have had the looser fragments of rock, which can be incorporated into the ice, gathered up and removed to the front, so that now the floor of the whole continent is so smooth and bare of fragments that there is nothing left for the glacier to get hold of. But during the movement of the glacier over the northern part of the United States, everything favored the mode of transportation and elevation of bowlders as described above.

As already shown,* the transportation of large bowlders, though impressive in view of the enormous masses moved, probably represents but an insignificant part of the work of erosion and transportation which took place during the Glacial period. Some would even regard the subglacial streams pouring out in front of every glacier, and surcharged with fine sediment, as the most important instruments of glacial transportation. How much of the glacial grist has been carried away by this process it is impossible to determine with accuracy. It will, however, be of some interest to learn the best attainable results.

In 1864 Dolfus-Ausset measured the fine sediment carried out by the stream from below the Unter-Aar Glacier, finding 132 grammes in a cubic metre of water. This corresponds to a yearly rubbing off of about 0·6 millimetre of rock from under all parts of the glacier's basins, or an erosion of one metre in 1,666 years—about two and a half times as much as water could do in the same period. It is not determined how much of the sediment came from sand washed under the ice by side streams, but it shows that the glacier does a considerable amount of work ("Matériaux pour l'Étude des Glaciers," 1864, vol. i, p. 276).†

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* See above, p. 136.

† Professor W. M. Davis, in "Proceedings of the Boston Society of Natural History," vol. xxii, 1882, p. 26.

M. E. Collomb has made some interesting calculations . . . based upon the observations of MM. Dolfus and Desor on the Aar Glacier in 1844 and 1854. These glacialists found that the amount of water discharged from this glacier between the 20th of July and 4th of August averaged 1,278,738 cubic metres daily—the minimum being 780,000 cubic metres, and the maximum 2,100,000 cubic metres. The area occupied by the glacier is estimated at fifty-two square kilometres. Now, supposing that the old glacier of the Rhône (the area of which M. Collomb estimated at 15,000 square kilometres, but which is actually under the truth) discharged its water at the same rate, it must have yielded a daily supply of 605,000,000 cubic metres. But if it be true, as all the facts would lead us to believe, that in the summers of the Glacial period more heat was received directly from the sun, then the daily discharge from such a glacier must have been greatly in excess of that amount.

. . . MM. Dolfus and Desor found that a litre of water from the Aar Glacier contained 0·142 gramme of fine mud; so that, according to Collomb's estimate of the area and daily discharge of the ancient Rhône Glacier, the water escaping from the latter must in summer time have transported 86,000,000 kilogrammes, or about 8,500 tons (English) per diem—an estimate which, considering the circumstances already referred to, is probably much under the actual truth.

According to Helland, the quantity of mud in the rivers that issue from the glaciers of Greenland is very variable, as may be seen from the table given by him, which is as follows:

			Grammes of mud in 1 cubic metre of water
River of the glacier of Jakobshavn	July 9,	1875	104
" " Alangordlek	" 10,	"	2,374
" " Ilardlek	" 17,	"	723
" " Tuaparsuit	August 6,	"	678
" " Umiatorfik	" 20,	"	75
" " Assakak	" 21,	"	208
" " Rangerdlugssuak	" 11,	"	278

Similar observations by the same geologist on the water issuing from the snow and ice-field of Justedalsbraeen likewise

showed that the quantity of mud varied in the different streams, and even in the same river. The result of ten different observations in the months of June and July gave a mean of 147·9 grammes of mud in 1 cubic metre of water. (See "Quarterly Journal of the Geological Society," 1877, p. 157.) *

Mr. J. E. Marr gives the following facts concerning the extent to which erosion is proceeding beneath some of the Greenland glaciers:

The erosive power of an ice-sheet is well seen by a glance at the observations made upon the rivers which flow into the fiords of Nagsugtok and Isortok, and which have their origin at the ends of the tongues of ice which occupy the valleys continuous with these fiords. The river from the first contained only 200 to 225 grammes of mud per cubic metre of water in the month of July; while the second, in the month of June, inclosed 9,129 to 9,744 grammes. This is compared with the amount carried by the Aar where it emerges from the glacier; it there contains only 142 grammes. The great difference presented by the rivers which fall into the two fiords is attributed to the fact that the ice moves with much greater speed toward the fiord of Isortok than toward that of Nagsugtok. It is calculated that the quantity of fine mud carried into the former of these fiords amounts to 4,062,000,000 kilogrammes per day. This mud is deposited in the interior of the fiord, which is filled up to such an extent in its upper portion that even flat-boats can not pass up it. †

The amount of material carried to the sea by the subglacial streams during the continuance of the Glacial period in North America could not be estimated, even though we knew the rate of transportation, unless we had more definite ideas than we now have of the length of time during which glacial conditions prevailed. But if, as is probably the case, the deposits of loess in the valley of the Mississippi are of

* Geikie's "Prehistoric Europe," pp. 231, 232.

† See "Geological Magazine," April, 1887, summarized in "American Journal of Science," vol. cxxxiv, 1887, p. 313.

glacial origin, these may at some time give us a partial clew to the length of the period.

Another method of estimating the amount of glacial erosion is by calculating the extent of the deposits over the glaciated region. Professor Newberry has estimated that the area south and west of the Canadian highlands, covered with glacial *débris*, is not much less than 1,000,000 square miles, and that the depth of the deposit over this broad marginal area can not be less, on the average, than thirty feet, and is probably twice that amount.* Professor Claypole found, upon comparing the estimates independently made in different counties of Ohio, Indiana, and Illinois, that the average depth for these three States was sixty-two feet, and

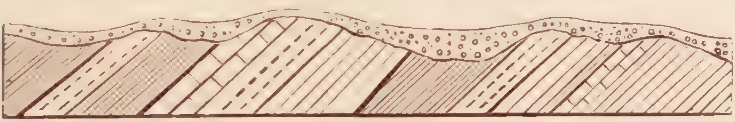

FIG. 76.—Ideal section showing how the till overlies the stratified rocks.

for Ohio alone fifty-six feet.† Recent extended experiments in boring for gas in western Ohio and eastern Indiana tend greatly to increase the estimate of Professor Claypole. There are whole counties in southwestern Ohio so deeply covered with glacial *débris*, that few of the citizens have ever seen the underlying rock. In other counties, where the rock occasionally crops out at the surface, the extensive spaces between are found to be valleys of immense depth, filled with the unstratified material of the ground moraine. In Professor Orton's recent report on the subject, giving the depth in fifty-three of the counties of Ohio as determined by the borings in 122 wells, the average is found to be upward of 90 feet (93 feet +). In some of the wells the depth was truly phenomenal, as in St. Paris, Champaign county, where, in one well, rock was not reached short of

* "School of Mines Quarterly," January, 1885, p. 7.

† "Glacial Erosion," by William M. Davis, "Proceedings of the Boston Society of Natural History," vol. xxii, pp. 19–58.

370 feet, and in another, 530 feet of till was penetrated, and the well abandoned before rock was reached. In Dayton, Montgomery county, the glacial deposit was found to be 247 feet; in Cridersville, Auglaize county, 300 feet; in Newark, Licking county, 235 feet; in Lebanon, Warren county, 256 feet; in Osborn, Greene county, 207 feet; in Hamilton, Butler county, 214 feet. These are all, perhaps, in preglacial valleys. But the average in various counties is certainly significant. In Auglaize county, six borings give an average of 141 feet; in Butler county, four borings, 116 feet.

With reference to the correctness of this representation, it should be remarked that borings prosecuted in this manner are more likely to give an underestimate than an overestimate of the real facts; for, as is well known, it is much easier and less expensive to drill through the sedimentary rocks than through deep deposits of till and looser drift; so that the aim of the prospectors is to begin their wells at points where the rock will be reached at as small a depth as possible. But so completely have the pre-glacial lines of erosion been obliterated in many places in Ohio, that it is impossible to calculate the proximity of the rock to the surface. Where the deepest drift was penetrated (530 feet in Champaign county), special effort was made to locate the boring where the superficial deposits were shallow; but, as the result proved, the surface indications were deceptive and a serious mistake was made, involving the contractor in great loss. It should, however, be observed that the deep well at St. Paris lies in the line of one of the great terminal moraines traced by Mr. Leverett across central Ohio, and where the depth of the glacial deposits is supposed to be excessive even in a moraine.

Mr. Upham estimates the mantle of drift that conceals the rocks in central Minnesota to be between 100 and 200 feet deep. In the Red River region, to the north, and over a wide belt stretching many hundred miles along the flanks of the Rocky Mountains, in the Dominion of Canada, the

depth is equally great. In the upper valley of the South Saskatchewan, at an elevation of about 4,000 feet above the sea, and from 600 to 700 miles west of the Laurentian axis, from which much of the glaciated material came, Mr. McConnell reports sections of till 125 feet deep.*

Professor Stone thinks the average thickness of the drift in Maine is between thirty and fifty feet. Mr. Upham's early calculations for New Hampshire were much more moderate, namely, ten feet.† But he now informs me that he would make a much higher estimate. Besides, in so mountainous a district, we should expect a thinner deposit to remain on the surface. The more rapid streams would transport a larger portion of the material to the sea than from the gentle slopes. Furthermore, the rocks of New Hampshire are better calculated to resist erosion than in some other portions of the country. Much of the soil of New Hampshire has been transported to the States farther south. No reliable estimate has been made of the average depth of the glacial accumulations over Massachusetts, Connecticut, and Rhode Island. There can be little doubt, however, that it is much greater than Mr. Upham makes for New Hampshire.

Professor Shaler ‡ sets down the total amount of drift in New England and its neighboring terminal moraines at 750 cubic miles, or more than the mass of the White Mountains. If evenly distributed, this would make a layer of about sixty-five feet.

Professor Lesley says the depth of the glacial drift over the northeastern counties of Pennsylvania is not less than fifty feet. This is on the summit of the Appalachian plateau, while the old valleys, filled with glacial *débris*, are some of them of great depth. One on Mehoopany Creek, in Wyoming county, is filled with drift to a depth of more than 235

* "Report of the Cypress Hills," 1886.

† "New Hampshire Geological Report," vol. iii, p. 293

‡ "Illustrations of the Earth's Surface: Glaciers," p. 58

feet. In this vicinity, Professor I. C. White * reports wells fifty feet deep which barely reach through the till, and this on elevations 1,335 feet above tide.

Great as these amounts may seem, the estimation of the erosion in the Scandinavian Peninsula by Professor Helland is still larger.† Helland, after conference with several geologists familiar with the region, estimates that the average depth of the drift over north Germany and northwest Russia is 150 German feet. This would indicate that the erosion from the Scandinavian Peninsula had been as much as 250 feet, since the material has nearly all been derived from Scandinavia, and the area of the source of supply in Scandinavia is only two fifths of that over which it was distributed.

This estimate of Helland for Scandinavia is not, however, greater than that of Professor Lewis for northern Pennsylvania. Here, on the Kittatinny Mountain, near the Delaware Water-Gap, this observer seems to have had a rare opportunity for directly measuring the eroding power of the ice at that point.‡ The summit of the mountain is crowned by compact strata of Medina sandstone, and trends northeast by southwest. The glacier surmounted the ridge on both sides of the Water-Gap, and extended twelve or fifteen miles farther south, while to the southwest the summit of the mountain was outside of the line of ice-movement, which just here is bordered by cliffs of the crowning Medina sandstone seventy feet high, as if the ice, in moving past them, had worn down the strata underneath to that amount. Professor Lesley, at the Minneapolis meeting of the American Association for the Advancement of Science, in 1884, took this as a measure of glacial erosion to illustrate how

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* See "Second Geological Survey of Pennsylvania on Wyoming, Lackawanna, Luzerne, Columbia, Montour, and Northumberland Counties G⁷," p. xiii.

† "Ueber die Glacialen Bildungen der nordeuropaischen Ebene, Deutsch. Geol. Gesell.," Zft. xxxi, 1879, p. 97.

‡ "Second Geological Survey of Pennsylvania Z," pp. 70, 90. See also above, p. 196.

small it was. But Professor Newberry well replied that, if there was that amount of erosion so near the margin, what must it not have been farther back, where the stream of ice had acted for an indefinitely longer time. Probably, however, Newberry is extravagant when he estimates that farther north the ice was ten times as thick, and continued to act ten times as long, making its erosive power one hundred times as great as that near the Water-Gap.*

The foregoing evidence of glacial erosion drawn from the extent of marginal glacial deposits is complicated by our ignorance of the extent to which disintegration of the rocks had proceeded before the Glacial period. Professor Whitney † and Mr. Pumpelly ‡ have specially pressed this point, as have Professor Sterry Hunt and the late Mr. L. S. Burbank,# to whom more credit is due than he has generally received for his early and sagacious suggestions upon the subject. The contrast between the glaciated and the un-

FIG. 77.—Ideal section showing result of disintegration in an unglaciated region. (Chamberlin.)

glaciated region, in the extent to which the surface rocks are disintegrated by subaërial agencies, is very striking. South of the glaciated region granitic masses and strata of gneiss

* "School of Mines Quarterly," p. 12

† "Climatic Changes," p. 7 *et seq.*

‡ "The Relation of Secular Rock-Disintegration to Loess, Glacial Drift, and Rock Basins," in the "American Journal of Science," vol. cxvii, 1879, p. 133 *et seq.*

"On the Formation of Bowlders and the Origin of Drift Material," in the "Proceedings of the Boston Society of Natural History," vol. xvi, November 19, 1873.

are often completely disintegrated to a great depth, sometimes amounting to scores of feet. What seem like beds of gravel (and which can be handled with a shovel) often prove to be horizontal strata of gneiss from which the cementing material has been removed by the slow action of percolating acids brought down by the rains. North of the glacial boundary it is very rare to find any such extensive evidence of disintegrating agencies. Since the ice passed over this region there has not been sufficient time for subaërial agencies to produce any marked disintegrating effect.

Now, it is with much plausibility contended that the action of the ice has been limited chiefly to the *transportation* of this disintegrated material, and that it has had little effect as an *eroding* agency. The strong point in this representation is, that there is little more loose soil over the margin of the glaciated region than would result from the simple transportation of the disintegrated material from the northern and central portions of the glaciated region to the marginal area. It certainly is clear, both from the necessities of the case and from actual observation, that the area of greatest erosion is nearest the center from which the ice radiated, and that, as the amount of deposition increased toward the margin, the erosion diminished.

The advocates of the great erosive power of glacial ice appeal, also, to the general appearance of the glaciated surfaces wherever exposed. The islands near Sandusky, in the western part of Lake Erie, for example, present some of the most marked indications of glacial erosion anywhere to be found, and the facts there are justly appealed to by Professor Newberry in support of the theory that the ice was a prominent agent in the formation of the basins of the Great Lakes.

As this is so important a region for glacial study, I will give somewhat in detail the result of my own recent observations. There are twelve or fifteen islands near the western end of Lake Erie, of which Kelly's, North Bass, Middle Bass, South Bass, and Pelee are the principal, each having

an area of several square miles, and none of them rising 100 feet above the surface of the lake. They all consist of the hard limestones of the Niagara series. In every instance, as one approaches them from the eastern side, his attention is attracted by the remarkable depth and continuity of the glacial grooves running nearly east and west upon them, and which rise out of the water, and continue to the summit of the islands, or until they are covered by the ground moraine which has not been washed away by the waves. In some

FIG. 78.—Glacial grooves on east side of South Bass Island, Lake Erie, running west 10° south.

instances, these grooves are two or three feet deep, and extend many rods in plain sight. Nor are they in all cases straight, but sometimes are extremely tortuous, winding along in their course like the channel of a sluggish stream. It is evident, in some cases, that the main features of these deepest grooves have been determined by preglacial or subglacial water-action, and that the ice, or the ground moraine under

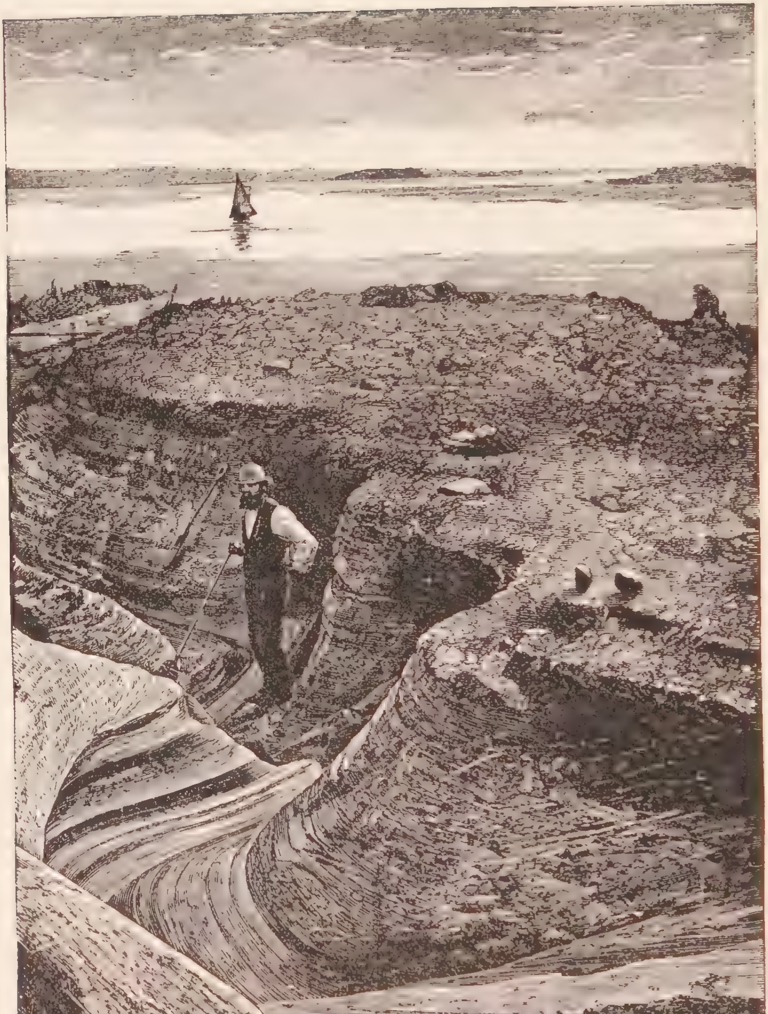

FIG. 79.—Tortuous grooves on Kelly's Island, Lake Erie. United States Geological Survey (Chamberlin).

the ice, has moved along in a previously formed mold, scouring it out and polishing it, and somewhat enlarging it. Thus it comes about that sometimes even the under surface of a projecting rock has been scratched and polished by the ice-movement. In case of the shallower grooves, two or three inches or less in depth, the abrupt variations are numerous, as if a pebble had encountered an obstacle to its direct movement, and turned aside to move onward in a new line of least resistance, the general course remaining substantially the same.

That there has been here considerable erosion by direct action of the ice there can be no doubt; but that it is less than some suppose is perhaps shown from the cross-striæ, which indicate four distinct but successive movements. The course of events was plainly as follows:

1. When the advancing ice filled the valley of Lake Erie, but had not surmounted the summit of the water-shed to the south, and before the Illinois lobe of ice had extended across Lake Erie's natural southwestern outlet, the ice-movement in Lake Erie was in the line of the longest diameter of the lake—i. e., southwest.

2. During the height of the Glacial period, when the ice surmounted the water-shed between the lake and the Mississippi basin, about one hundred miles to the south and from five to seven hundred feet higher, the movement of the ice was very nearly north by south. There was then no opportunity for the ice to escape from the southwestern end, because of the larger general movement of the glacier across its pathway. So powerful was this movement in a southerly direction that deep north-and-south channels were eroded in all the islands.

3. But, upon the retreat of the ice to the water-shed, and the withdrawal of the glacier, which crossed its way on the southwest, the former westerly line of movement was at once resumed. Each later movement has done much to obliterate the marks of the earlier. Upon the eastern slopes this obliteration is sometimes complete. But wherever there was a

lee side of a prominence in which a north-and-south glaciated surface could be protected from the force of the eastern current, we find that it was protected, and the glaciated surface is as fresh on the removal of the soil as it is anywhere. In places the beveled edges of earlier grooves are perfectly distinct where the second cross-movement has obliterated a part of a groove, and left still untouched the portion of the earlier groove which was protected by a ridge. Within a half mile of each other there are grooves several inches in depth running at right angles to each other. For instance, upon the west side of Gibraltar (which is a small, rocky island at the mouth of Put-in Bay, close to South Bass Island), there are deep grooves, running north by south, made by the second movement; but they were perfectly protected by the rock, which received the brunt of the third movement as it came from the east. One half mile west, and a little south of this point on the main island, where there is a shallow valley across the island, the east-and-west grooves are equally striking. This was doubtless the movement whose record is left in the moraine of the Maumee Valley, as already described by Gilbert.*

4. There were also indications of still a fourth movement, which set in when the ice had receded so far that the obstruction presented by the elevation of the water-shed to the south would no longer compel a westerly movement. But, when the ice-front was between these islands and the south shore, the movement would again be, according to theory, to the south, at right angles to the first and third movements. This last movement, however, was probably feeble and not of long continuance. Still, there are some signs of it in the shape of shallow striæ across the second set of east-and-west furrows. While all this is witness to the efficiency of ice as an eroding agency, it conveys the impression that the erosion accomplished by each successive movement was concentrated in special channels, and was nowhere excessive.

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* See p. 207

Fig. [illegible].—Section of east and west glacial furrows, on Kelly's Island. Till rests immediately on the rock, with washed pebbles at the surface.

The following very important extracts concerning glacial erosion, from the recent report of Mr. I. C. Russell, need no introduction and no comment:

That the rock-basins in the high Sierra were excavated by glaciers the writer finds no reason whatever to question. They frequently occur at the lower limit of a steep slope, which is polished and grooved, and bears every indication of having been abraded by glacial action. In such cases the slope and the direction of the furrows show that ice once descended into the basin. On examining the opposite portion of the rim of the depression, glacial markings of the same character will be found. The proof is thus positive that the ice descended into the depressions now filled with water, and emerged from them again to continue its course. As there is no other agent known capable of eroding hollows in solid rock having the character

FIG. 81.—Same as the preceding. (Courtesy of M. C. Youngglove.)

of the basins observed in the high Sierra, it seems evident that the theory of the formation of rock-basins proposed by A. C. Ramsay, from evidence obtained in Scotland and Switzerland, is substantially correct, and furnishes the true explanation of the origin of the examples before us.* The manner in which the power of moving ice is directed so as to erode depressions may be open to discussion, but the conclusion that rock-basins are a result of glacial action is now too strongly supported by facts to be questioned. . . .

On examining the numerous lakes more critically, one finds that many of them occupy depressions in morainal *débris*, or are confined by terminal moraines. In numerous instances, however, as in Bloody and Gibbs Cañons, at the head of Rush Creek, and all about Mount Lyell and Mount Ritter, the fact that the lakes occupy depressions in solid rock is beyond all question. One may walk entirely around many of them without stepping off rock in place. . . .

As some writers—especially those who are given to solving the mysteries of Nature from their closets—have thought that lakes filling true rock-basins are a rarity, and have even doubted whether they exist at all, we shall be interested in examining this result of glacial action, while we wait for our mule-train to join us. The stream from above cascades over hundreds of feet of rock before reaching the lake ; on either hand the overshadowing cliffs tower upward for a thousand feet ; and we can walk along the lower border of the lake and find solid rock all the way across the cañon. There is no doubt, therefore, that the lake occupies a basin in solid rock. The ledge confining the waters rises in places almost perpendicularly to the height of over a hundred feet above the lake surface, and indicates by its rounded contour and polished and striated sides that the ice was once forced up from the basin, now filled with water, and flowed over the ledges and down the gorge. The sounding-line tells us that the bottom of the basin is fifty-one feet below the lake surface. We thus have a rock-basin of considerable depth, in the path of a glacier,

* "On the Glacial Origin of Certain Lakes," etc., "Quarterly Journal of the Geological Society of London," vol. xviii, 1862, pp. 185–204

the unmistakable markings of which descend into it on the upper side and emerge again at its lower margin.*

Fig. 82.—Glacial furrows on west side of South Bass Island, running west 10° south.

There is so much general interest in the question as to the formation of the Yosemite Valley that we append the remarks of the same high authority concerning it:

* "The Quaternary History of Mono Valley, California," pp. 281, 368, 369.

It is the opinion of the writer that the excavation of many of the valleys of the Sierra Nevada began long previous to the Quaternary, and are in fact relics of a drainage system which antedates the existence of the Sierra as a prominent mountain-range.

Those who seek to account for the formation of the Yosemite and other similar valleys on the western slope of the Sierra by glacial erosion should be required to point out the moraines deposited by the ice-streams that are supposed to have done the work. The glaciers of this region were so recent that all the coarse *débris* resulting from their action yet remains in the position in which it was left when the ice melted. If the magnificent valleys referred to are the result of glacial erosion, it is evident that moraines of great magnitude should be found about their lower extremities. Observation has shown that *débris* piles of the magnitude and character required by this hypothesis are notably absent.

It is perhaps not disgressing too far to state that the writer, while visiting the Yosemite, could not avoid adopting an hypothesis advanced some years since by J. D. Whitney, to the effect that the main characteristics of the valley are due to dislocation ; or, in other words, that the orographic block beneath the valley has subsided. No facts were observed, however, conflicting with the conclusion of Clarence King that the valley was occupied at least in part by glacial ice. The majestic domes of the Yosemite region have not been rounded by glacial action as some writers have supposed, but have been produced by the weathering of granite, in which a concentric structure on a grand scale was produced when the rocks were in a plastic condition.*

Another illustration of the anomalous erosive power of glacial ice is seen in the so-called *cirques* so abundant in glaciated regions containing mountains. Here, again, we are under great obligations to Mr. Russell for his careful report upon these features of the high Sierra. Little is to be added to his discussion of the subject.

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* "The Quaternary History of Mono Valley, California," pp. 350, 351.

One of the most striking features in the sculpturing of the high Sierra is furnished by the grand amphitheatres or *cirques*, occurring about the more elevated peaks and crests. These are deep semicircular excavations, bounded on all sides, except that through which the drainage escapes, by bold cliffs or by perpendicular walls from a few hundred to more than a thousand

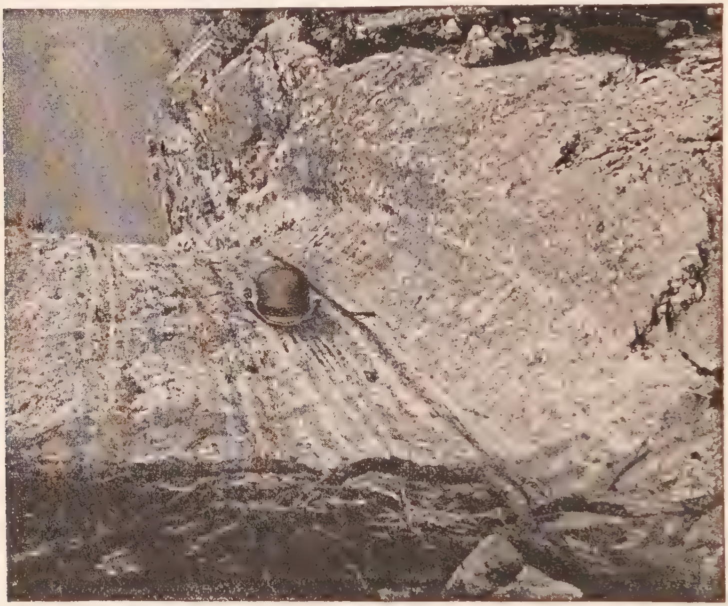

FIG. 83.—Glacial furrows on Gibraltar Island, one half mile from preceding, but running nearly north and south.

feet in height. The bottoms of these excavations are often depressed below that portion of the rim through which the drainage escapes, and form rock-basins; at other times the basins are partially inclosed by *débris*, and in some instances they have well-formed terminal moraines across their outlets. In these hollows there are transparent lakes of azure blue, which reflect the grandeur of the sheltering walls with wonderful distinctness from their unruffled surfaces. A horizontal cross-section of a *cirque* is semicircular or horseshoe-shaped, and in certain portions of the range these are so numerous that they give a scalloped contour to the faces of the cliffs. The

interiors of some of the amphitheatres are terraced in the same manner as are the bottoms of the cañons leading from them, a feature which has been observed in the *cirques* of the Rocky Mountains as well. Nearly all the various branches of the ancient glaciers of the high Sierra headed in deep recesses of the character above described. In places the *cirques* occur on either side of a fragment of table-land, and have been eroded back until only a knife-edge of rock, so narrow and broken that the boldest mountain-climber would hesitate to traverse it, is all that divides one profound depression from another. Examples of this nature are common about Mounts Lyell and Ritter, and find a number of typical illustrations in the cliffs of the Kuna and Koip crests. At the head of Rush Creek are a number of separate *cirques*, each holding a gem-like lakelet, in which the various branches of the stream draining the basin have their source. Silver Creek heads in a magnificent amphitheatre formed by the union of several *cirques*, which during the height of the Glacial epoch was completely filled with *névé*. On the south side of Kuna and Koip peaks are two vast amphitheatres which rank among the finest in the Mono region. . . . No topographic delineation or word description can convey the impressive grandeur of some of these vast, shrine-like recesses that have been sculptured during the lapse of centuries from the rugged cliffs of the high Sierra.

In general the *cirques* open northward, but many exceptions to this rule can be found, especially about the head-waters of Rush and Silver Creeks.

It is in the *cirques* about the higher peaks that living glaciers are still found, and those not harboring perennial ice are deeply filled with snow during a large portion of the year. The slow melting of the snow and ice in these reservoirs feeds the rills which join one with another to form the creeks flowing into Lake Mono. The balance between the climatic conditions favorable to the existence of glaciers and those which insure their disappearance is here nicely adjusted, and, should the equilibrium shift to the side of greater congelation, these ancient *cirques* would be the first points to exhibit the changed conditions. They were the fountains which gave birth to the

ancient glaciers, and were also the last strongholds to be abandoned when the reign of ice approached an end.

Such amphitheatres are known in all mountain-regions where glaciers have existed. It has been the good fortune of the writer to examine them on some of the higher peaks of Colorado and New Mexico, about the crests of the Wahsatch and East Humboldt Mountains, as well as in Switzerland and New Zealand. Their origin is somewhat problematic, and has occasioned much discussion, as is well known to all who have followed the growth of glacial literature.

In an article on the formation of *cirques*, by T. G. Bonney,* an attempt was made to prove that these peculiar features of mountain sculpture are the result of stream-erosion, and owe few if any of their characteristics to ice-action.

The studies of B. Gastaldi,† on the effects of glacial erosion in Alpine valleys, led him to reject Bonney's hypothesis, and to conclude that they are a result of ice-erosion.

The most extended as well as the most instructive essay concerning their formation that has come under the writer's notice is from the pen of Amund Helland, entitled "On the Ice-Fiords of North Greenland, and on the Formation of Fiords, Lakes, and Cirques in Norway and Greenland."‡ In this essay a clear and concise description of the *cirques* of Norway, Switzerland, and other regions is given, together with a brief summary of the various hypotheses that have been advanced in explanation of their origin. Strong evidence is also presented to show that they are a result of glacial action. In Helland's essay are included the views of Lorange, of the Norwegian Royal Engineers, who arrived at the conclusion that they are formed principally by the effects of great changes of temperature in the vicinity of glaciers. We quote Lorange's observations and conclusions as stated by Helland:

"Under the glaciers in *cirques*, where a space intervened between the bed of the *cirque* and the ice, he saw a great many

* "Quarterly Journal of the Geological Society," London, vol. xxviii, 1872, pp. 312–324.

† Ibid., vol. xxix, 1872, pp. 396–401.

‡ Ibid., vol. xxxiii, 1873, pp. 142–176.

stones, some of which, sticking fast in the glacier, were quite lifted up from the bed of the *cirque*, while others were touching or resting on it; he thinks it probable that, as the temperature around the glacier constantly varies about the freez-

Fig. [illegible].—Glacial groove on Middle Bass Island, running nearly east and west, with a north-and-south groove crossing it. Notice the beveled edge of the east-and-west groove, which is here descending to the west.

ing-point, the incessant freezing and thawing of the water in the cracks in the rock may split it, and the glacier may do the work of transportation for the fragments thus broken loose. On examining the interior of an empty *cirque*, we observe that a bursting, not a scooping out, of the rocks has taken place."

The writings of Penck, Löwl, and other European geolo-

gists might be cited here, but it is not my intention to review the entire literature of the subject.

Sufficient observations have been recorded to show not only that *cirques* are of nearly world-wide distribution, but that they are confined to glaciated regions, and are not found in mountains where undisputed records of glacial action are absent. This in itself is good evidence that they have resulted from glacial erosion. The same conclusion is indicated by the fact that as a rule they open northward—that is, they occupy positions where glaciers first appear when a lowering of temperature renders their existence possible, and where they linger longest when the climate ameliorates. It thus seems unnecessary to discuss in the present paper the various hypotheses which refer their origin to water erosion, crater elevation, etc.

The descriptions presented in the essays we have cited, together with the observations of the writer, show that the *cirques* of the high Sierra are typical of their class, and present all the features to be seen in other similar regions. It is thus rendered evident that, if we can arrive at an acceptable explanation of their origin, it should explain the like phenomena in other regions as well. The writer has no mature theory to offer, but hopes to contribute something toward the desired end.

It is usually difficult to draw a definite line between a glacial *cirque* and the cañon leading from it. One is a continuation of the other. It is evident, also, that the walls inclosing a *cirque* have many features in common with the scarps so frequent in glaciated cañons. When the *cirques* themselves are terraced, this analogy is rendered still more complete. The writer's studies in the high Sierra and elsewhere have led to the conclusion that such scarps and *cirques* result mainly but not wholly from glacial action. The initiation of the process, at least in the high Sierra, as in the case of many glacial cañons, must have been by subaërial erosion.

Lorange's observations show that when a *névé* fills a *cirque* it is capable of removing blocks of rock from the inclosing walls. The fact that these walls are rough and angular, instead of smoothly polished, is proof that there is but little

abrasion during the settling and consolidation of the *névé* in the amphitheatres in which it accumulates. At the bottom of the depressions, however, the conditions are different. Intense glaciation there takes place, as is attested by the rounded and striated surfaces, and by the occurrence of rock-basins. The ice filling a *cirque* impinges with great weight upon its bottom and in its motion outward tends to deepen the excavation. At the same time the blocks loosened from the walls of the *cirque* are carried away by the outward flow of the ice. There are thus at least two processes which unite in enlarging and deepening these peculiar features of glaciated mountain-tops.

When a glacier leaves a *cirque* and flows down a cañon the grade of which is uneven, the erosion of the ice-stream will also be uneven. The reason is that the ice in descending a steep slope exerts its greatest force at the base of the incline in the same manner as in the excavation of *cirques*. The tendency of a moving ice-stream in descending a steep slope is to increase the inequalities of its bed; this tendency, it seems probable, will lead to the formation of both scarps and *cirques* when the drainage of a high-grade valley is changed from a liquid to a solid form. To illustrate: The grade of mountain streams increases toward their sources, and when their gorges become occupied by ice, the irregularities of their channels —caused principally by the meandering of streams, thus leaving projecting bosses on either side—may cause ice-cascades in the glaciers. An ice-cascade exerts the greatest erosive power at the base of the scarp which it descends, thus augmenting the inequality. At the same time the cañon is broadened and the minor features resulting from stream-erosion are erased. The steeper the grade the more pronounced would be the action of the ice in remodeling and strengthening the major inequalities of its bed. The resulting scarps and terraces should therefore be most numerous and best defined near the heads of the channels in which they occur.*

The prevalence of *cirques* is also graphically described by Dr. G. M. Dawson in his "Report upon the Forty-ninth

* "The Quaternary History of Mono Valley, California," pp. 352–355.

Parallel." Speaking of the streams which rise in the Rocky Mountains, he says:

The upper ends of the valleys surrounding the higher peaks and ridges are generally very abrupt and take the form of *cirques*, or amphitheatrical depressions of great depth, in the mountain-sides. The backs and sides of these are often nearly vertical, and they are sometimes only separated laterally, by steep, knife-edge-like ridges, the crests of which form the most practicable paths to the summits. Each of these upper terminations of the valleys generally also shows a small lake or pond in the hollow of the surrounding cliffs, the basin of which has evidently been formed by glacier-ice—which must here have been descending almost vertically—in the moraine matter or shattered rocky floor. . . . The water of the smaller lakes in the upper ends of the valleys, as seen from the heights around, is of a beautiful semi-opalescent indigo-blue, and must be of considerable depth.*

These facts confirm the theories of the leading glacialists of Europe—for instance, Dr. Albrecht Penck, who ascribes the excavations of the most important lake-basins in Bavaria, like the Ammer See and Wurm See, to glaciers, and states that "a lake-basin filled with water or sediment lies at the mouth of each of the Alpine valleys through which glaciers protruded in ancient times." †

The Scotch lochs, and the rock-basins of Norway, would seem to be due to the same cause. It is probable also that the fiords of Norway and of British Columbia owe their greater depth near their heads to the same anomalous influence of ice-erosion. Most of the arguments urged against the theory are based upon *à priori* reasons urging the impossibility of any such result from such a cause. Of this more will be said when speaking a little later of the irregular deposition of glacial *débris* underneath the moving ice.

Not enough is known about the nature of ice to affirm

* Page 245.

† Quoted by Newberry, in "School of Mines Quarterly," January, 1885, p. 10.

that it does not conform to the law of other moving fluids. Probably there is no reason why an ice cascade should not produce results of erosion analogous to those of a waterfall.

Summarily stated, our conclusions are that, like everything else connected with the action of such a complicated cause as that brought into view in the production of glacial phenomena, the exact extent of its erosive and transporting power is difficult to determine. The action of ice over the glaciated region took place after other forces had been in full operation during long ages; and hence it is often impossible to separate the effects of the second cause from those of the first.

But there can be no doubt that running water is by far the most efficient of all eroding agencies which have given shape to the contour of the continents. Most important results follow from the power of water to act as a solvent. Extensive regions have been undermined and lowered through the removal by water of the soluble salts. Such has perhaps been the origin of many of the valleys of the Appalachian region and of some of the great lakes of the world. Running water is also a most effective mechanical agency, continually acting along the natural lines of drainage. The sand and gravel rolled along over the bottom of a rapid stream of water act like a rasp or a saw, and have everywhere worn deep narrow channels across the slowly rising mountain-chains. Water as an eroding agency has had a great advantage over ice in the far greater length of time during which it has been in the field to operate.

Still, it can not be doubted that ice has had no small part in transforming the appearance of the portions of the world to which it has had access. Of this the evidence is abundant in the great number and size of the bowlders scattered over the glaciated region, hundreds of miles from their native ledges, and weighing hundreds and even thousands of tons.

Inasmuch as ice is frozen water, its melting furnishes the torrents to aid in the transportation. The finely comminuted material ground up underneath the ice is largely carried away

by the torrential subglacial streams continually pouring out from the ice-front. It is doubtful if the larger part of the glacial grist is not thus transported far beyond the limit of the glaciated region.

Notwithstanding the great waste, the extent of the glacial deposits yet remaining over the southern portion of the glaciated region is immense. Probably not less than 1,000,000 square miles of territory in North America is covered with an average depth of fifty feet of glacial *débris*, forming the most permanently productive portion of the continent. It is in the extent of these glacial deposits, and in the certainly great amount of transportation by subglacial streams, that we have our most certain and impressive evidence of the enormous activity of erosive agencies during the Glacial age.

FIG. 85—Iowan bowlders south of New Hampton, Iowa. (Photo by Calvin.)

CHAPTER XI.

DRUMLINS.

"DRUMLIN" is the name now used to designate the class of glacial accumulations which Professor Hitchcock originally called "lenticular hills." These abound in the vicinity of Boston, and largely give character to the scenery of the three northeastern counties of Massachusetts. They are not, however, evenly distributed over the region. Familiar examples of them are Beacon Hill, Boston; Bunker Hill, in Charlestown; Breed's Island Hill, beyond East Boston; Green Hill, in Winthrop; Powder-Horn Hill, in Chelsea; Mount Revere; Mount Washington, in Everett; Tuft's College Hill; Winter Hill and others, in Somerville; Bigelow Hill, in Brighton; White's Hill, in Watertown; Owl Hill, in Waltham; Mount Ida, Prospect, Institute, and Oak Hills, in Newton; Corey's and Walnut Hills,

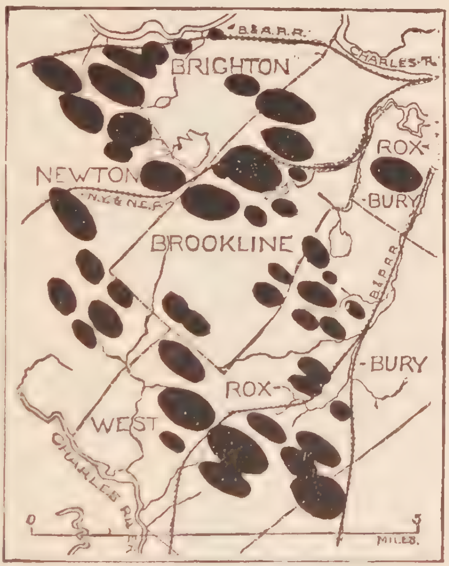

FIG. 86. Drumlins in the vicinity of Boston. (Davis.)

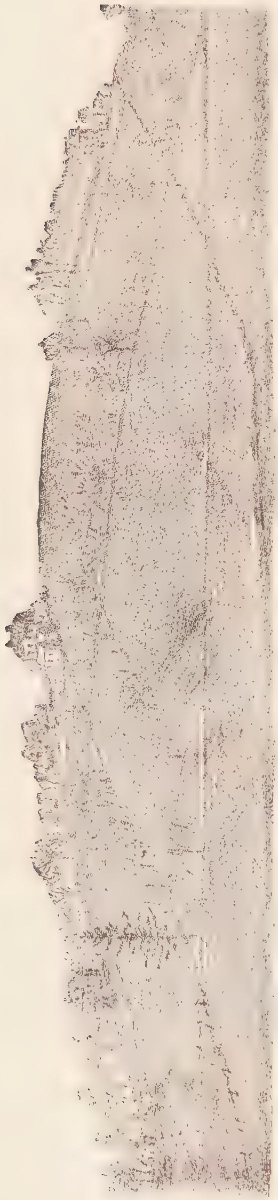

Fig. 87.—Corey's Hill, Brookline, Massachusetts. A typical drumlin. (Davis.)

in Brookline; Parker's Hill, in Roxbury; Bellevue and the Clarendon Hills, in West Roxbury; Brush Hill, in Milton; Jones's Hill, Mount Ida, and Pope's Hill, in Dorchester; Wollaston Heights, Forbes, President's and Great Hills, in Quincy; Great and King Oak Hills, in Weymouth; Baker's, Otis, Prospect, and Turkey Hills, in Hingham; Scituate and Bear Hills, in Cohasset; Strawberry and Telegraph Hills, in Hull; and the hills of Deer Island in the harbor. More than a hundred others of the same character occur within this area.

Mr. Warren Upham's description of these interesting features of the landscape is most complete and satisfactory:

These hills vary in size from a few hundred feet to a mile in length, with usually half to two thirds as great width. Their height, corresponding to their area, varies from twenty-five to two hundred feet. But, whatever may be their size and height, they are singularly alike in outline and form, usually having steep sides, with gently sloping, rounded tops, and presenting a very smooth and regular contour. From this resemblance in shape

to an elliptical convex lens, Professor Hitchcock has called them *lenticular hills*, to distinguish these deposits of till from the broadly flattened or undulating sheets which are common throughout New England.

The trend, or direction of the longer axis, of these lenticular hills is nearly the same for all of them comprised within any limited area, and is approximately like the course of the striæ or glacial furrows marked upon the neighboring ledges. In eastern Massachusetts and New Hampshire, within twenty-five miles of the coast, it is quite uniformly to the southeast, or east-southeast. Farther inland, in both of these States, it is generally from north to south, or a few degrees east of south; while in the valley of the Connecticut River it is frequently a little to the west of south. In New Hampshire, besides its accumulation in these hills, the till is frequently amassed in slopes of similar lenticular form. These have their position almost invariably upon either the south or north side of the ledgy hills against which they rest, showing a considerable deflection toward the southeast and northwest in the east part of the State. It can not be doubted that the trend of the lenticular hills, and the direction taken by these slopes, have been determined by the glacial current, which produced the striæ with which they are parallel.*

FIG. 88.—Outline of drumlins in Boston Harbor. (Davis.)

* "Proceedings of the Boston Society of Natural History," vol. xx, pp. 224, 225.

To this may be added the following interesting remarks by Professor William M. Davis:

The general uniformity of outline in any single region is very noticeable; indeed, the view from the summit of a commanding drumlin, in the center of a group, shows as characteristic a landscape as that seen in looking from the Puy-de-Dôme over the extinct volcanoes of Auvergne. Moreover, the control that drumlins exercise over the laying out of roads and the division of property is so complete in districts where they abound, that it is the rule to find roads, fields, gardens, and even houses oriented in obedience to the march of the old ice-invasion. About Boston there are hundreds of dwellings whose walls thus stand in close parallelism with the glacial scratches on bed-rock beneath them.*

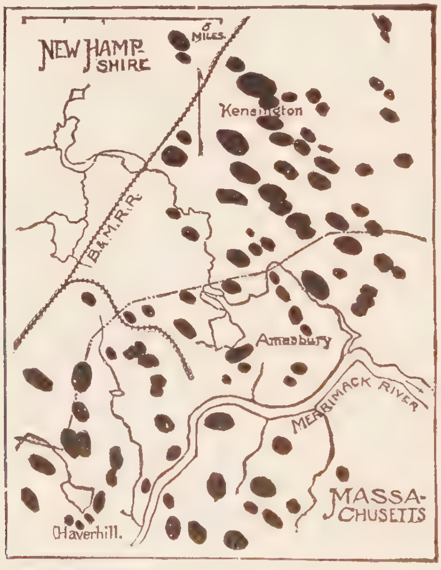

FIG. 89.—Drumlins in northeastern Massachusetts. (Davis.)

Besides the groups of drumlins so prominent in the vicinity of Boston, there are two or three others deserving of mention, and which may perhaps be brought into connection with them.† One of these, about eight miles wide and twenty long, and containing thirty or forty well-marked individual hills of the character described, follows the coast from Beverly to Newburyport. Parallel to this there is a belt of country, about

* "American Journal of Science," vol. cxxviii, 1884, p. 409.

† See map, p. 338.

four miles wide, over which scarcely any of these hills are found. Still farther inland, a longer range can easily be traced. Beginning in the vicinity of Portsmouth, N. H., this interior series is well developed, in a southwest direction, through Rockingham county to Amesbury, Mass. Thence, on, it completely covers the townships in Essex county on either side of the Merrimack River to Lowell, and continues, with little interruption, through Middlesex county to the vicinity of Fitchburg, Worcester county. To a limited extent these same typical hills abound still farther west through the northern part of Worcester and Franklin counties to the Connecticut River. Areas of them are also reported running up from Ashburnham, Mass., to Weare, N. H.; also in the western part of Cheshire county, N. H., and in the vicinity of Worcester, Mass., as well as about Amherst and in the northeastern part of the State of Connecticut.*

The following additional facts have been collected by Professor Davis: †

A fine series of drumlins stretches from about Spencer, Mass., to Pomfret, Conn., but the detailed study that it would well repay has not yet been attempted. Members of this series occur near Charlton station, Boston and Albany Railroad, with their bases at an elevation of nine hundred feet above sea-level, and others stand still higher. The portion of the group in Connecticut is described by Percival as follows: "The district extending north from Hampton, through

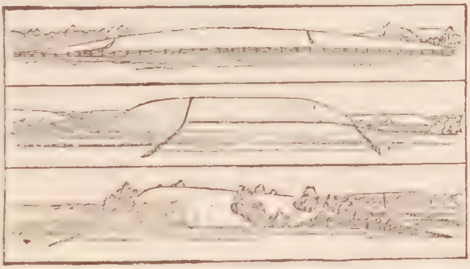

Fig. 90.—Outline of parallel drift-hills, in central New York. (Davis.)

* Upham, in "Proceedings of the Boston Society of Natural History," vol xx, pp. 231, 232

† "American Journal of Science," vol. cxxviii, pp. 410, 411.

Abington, Pomfret, and Woodstock, is characterized by a series of very smoothly rounded, detached hills, in which the rock is usually entirely concealed. These form a striking contrast with the longer and more continuous [rocky] ridges of the adjoining formation." * Professor G. H. Stone reports that drumlins of large size, like those about Boston, have not been found in Maine. Western New York, between Syracuse and Rochester, presents a surprising number of parallel north-and-south drift-hills, probably familiar to many travelers by rail. Some of them are so long, smooth, and even, that the country thereabout has been described as *fluted*. These were long ago described by Professor James Hall, in his "Geology of the Fourth District of New York" (1843); since then they have been strangely neglected until examined by Dr. L. Johnson, who has lately published a paper, † entitled "The Parallel Drift Hills of Western New York." Some of the ridges are "two or three miles long, and attain elevations of one or two hundred feet above the intervening valleys; but the greater number are shorter and steeper. Many of them were, when first cleared of timber, very steep at their north ends, and on their east and west sides; but, with very rare exceptions, the southern slope is gradual." These and other irregularities of form

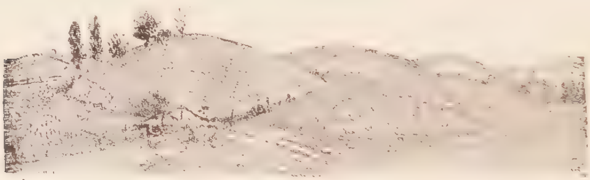

FIG. 91.—Drumlins in Wisconsin. (Chamberlin.)

may require that some of the hills of this region should be separated from drumlins as here defined. In Wisconsin, the drift-hills, as described by President T. C. Chamberlin, "are arranged in lines, and their longer axes invariably lie parallel to the movement of the ice. In some localities, especially

* "Geology of Connecticut," 1842, pp. 256, 461, 479, 485.

† "Transactions of the New York Academy of Sciences," vol. i, 1882, p. 77.

in Dodge and Jefferson counties, these are mainly replaced by long parallel ridges, sometimes several miles in length, with corresponding linear marshes interspersed. These correspond accurately to the direction of the ice-motion." * According to Mr. Upham, drumlins are not found in the abundant drift of Minnesota. A few examples are mentioned for Pennsylvania, near its western border, by Professor Lewis. †

In endeavoring to account for this class of hills, two or three facts are of special importance: 1. The material of which they are composed is very heavy and compact—almost as heavy and compact, indeed, as ice. Such masses could not have been shoved along bodily beneath the ice. In fact,

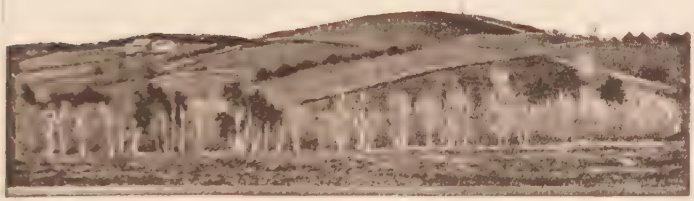

Fig. 92.—Drumlins in Goffstown, N. H. (Hitchcock.)

there would seem to be no reason why they might not resist the erosion of the glacier almost as well as many of the softer rocks did, especially when we remember that the pressure of the ice on the bottom need not have been uniform, but greater in some places than in others. 2. There are many indications that these hills were formed by accretion under the ice, there being, as Mr. Upham has shown, a tendency to lamination or coarse glacial stratification in the structure of

* "Geology of Wisconsin," vol. i, 1883, p. 283.

† "Second Geological Survey of Pennsylvania, Z," pp. 29, 188.

the hills.* 3. They are not characterized by kettle-holes. The surfaces are remarkably symmetrical, as if having been smoothed over by design, and all the irregular depressions are filled with homogeneous earth. 4. Up to one hundred feet above their base, the flanks of these hills in Massachusetts and New Hampshire are frequently covered with the water-worn deposits hereafter to be described and known as kames, and which are the very last work done by the ice at the points where they are found. The drumlins are, therefore, earlier than the kames.

In structure these hills resemble the lower portions of till, or the ground moraine. They are only imperfectly stratified, and very compact, and filled with foreign and finely striated stones. They are, without doubt, a true glacial deposit; but how comes the deposit to be heaped up in these localities in such vast and shapely masses? Professor Shaler surmised that they were but the remnants of a continuous ground moraine which had been eroded from the whole country, except where it was protected by pedestals or underlying rock which served to break the force of the beating waves of the ocean.† To this ingenious theory there are two fatal objections: 1. Drumlins are frequently found where there are no rocky pedestals to protect their bases. 2. They occur in the interior far above any height to which it is supposed the ocean has reached since the Glacial period. "The altitudes at which they occur vary from the level of the sea to fifteen hundred feet above it on the height of land between the Merrimack and Connecticut Rivers." ‡ Mr. Clarence King would explain them as marking places in the great continental glacier where streams of water which had run for some distance in superficial channels along the surface of the glacier and collected a great amount of *débris* from the medial moraines, had finally plunged through a *moulin* into

* "Proceedings of the Boston Society of Natural History," vol. xx, p. 223.

† Ibid., vol. xiii, pp. 196–233.

‡ Ibid., vol. xx, p. 233.

a deeply hidden subglacial river.* Here, it is thought, vast cavities might be formed in which these accumulations would take place, while, by the movement of the ice, the crevasse might be transferred farther down, and so the accumulated deposit be subjected to the pressure and sculpturing power of the ice.

Mr. Upham speaks on the subject as follows: "The finely pulverized detritus and glaciated stones in the bottom of the ice-sheet had a tendency to lodge on the surface of any deposit of the same material. When such banks of the lower till became prominent obstacles to the ice-current, its leveling force was less powerful than this tendency of adhesion which continually gathered new material, building up these massive rounded hills." † Mr. Upham remarks upon the partial parallelism of these ranges of hills with the extreme terminal moraine, and, with his usual perspicacity, notes that both the glacial striæ and the trend of the axes of the lenticular hills nearest the coast in Essex and Suffolk counties, bear much more easterly than they do even a few miles in the interior. This points with much force to the effect which would be produced upon the movement of the ice near its margin when it had receded a considerable distance from the south, but especially from the east, where the waters of the Atlantic had access to the glacier along the margin of what is called the Gulf of Maine. When the waters of this gulf had eaten the ice well away into the Massachusetts shore, and thus removed the barrier to the east, the line of least resistance would be in that direction, and the current would naturally swing out toward the open sea.

While recognizing the force of all Mr. Upham says, I can not forbear repeating an additional suggestion of my own

* I do not know as Mr. King has anywhere published these views, nor, indeed, as he would now be willing to own them, as here stated. They were given me in personal conversation, and contain so much that is worthy of consideration, that I venture to repeat the theory.

† "Proceedings of the Boston Society of Natural History," vol. xx, p. 234.

made at the same time,* namely, that these hills perhaps represent an earlier moraine than that on the south shore of New England—i. e., one which was formed when, on the first advance of the ice, it had reached the latitude of Boston, and where for some reason it paused until great accumulations had taken place along its front; that afterward, upon a fresh advance, these accumulations were overrun by the ice without being leveled; being merely sculptured by it, and readjusted to the changing line of general movement; and that, finally, the retreat of the ice was so rapid over this region that there were no marked terminal accumulations; but the superglacial *débris* settled gently over the whole country, constituting the more highly colored superficial blanket of *débris* called by Hitchcock "upper till," and furnishing the larger and more angular bowlders characteristic of the superficial deposits. I find also that Professor Charles Hitchcock had made the same suggestion as early as 1876.†

The long discussion concerning the origin of these singular hills would seem to have been brought to a close by the careful summary and discussion of facts given by Professor Davis, from which we have already quoted:

The first clear reference to drumlins, as directly dependent on glacial action for their form, was made by M. H. Close.‡ They are here said to be parallel to the neighboring striæ, and hence, like these, dependent on the ice-sheet for their present attitude and form. The same conclusion is presented in a paper of 1866, when the name *drumlin* was first specially proposed for them. Still later, when describing the physical geography of the neighborhood of Dublin, Close writes, "It is perfectly certain that it must have been the rock-scoring agent which produced the bowlder-clay ridges." Besides this, Kinnahan and Close, in a pamphlet of 1872, stated their opin-

* "Proceedings of the Boston Society of Natural History," vol. xx, p. 218; also, "Prehistoric Andover," p. 4.

† Ibid., vol. xix, p. 66. Professor N. S. Shaler now favors this view; see the "Seventh Annual Report of the United States Geological Survey," 1888, p. 321.

‡ "Journal of the Royal Geological Society of Ireland," vol. i, 1864, p. 3.

ion that drumlins were formed in a way "similar to that by which a stream of water often makes longitudinal ridges of sand in its bed."* This is to my mind the best suggestion yet given to account for them.

J. Geikie wrote as follows: "The remarkable linear direction of certain mounds of bowlder-clay in some districts of the Lowlands, agreeing as this does with the general bearing of glacial markings of the same localities, induces us to believe that we have here, with certain modifications, the original contour of the till after the superincumbent ice-sheet had disappeared"; † but he believed that these forms may be also in part dependent on marine erosion. In the "Great Ice Age," the same author briefly mentioned "the series of long, smoothly rounded banks or drums, and sow-backs, which run parallel to the direction taken by the ice," and regarded them as very little modified from their glacial form. They are "produced by the varying direction and unequal pressure of the ice-sheet," and are "the glacial counterparts of those broad banks of silt and sand that form here and there upon the beds of rivers." Dr. L. Johnson says that he accepts Geikie's explanation, and applies it to the New York ridges which were "formed underneath the glaciers by alternations of lateral pressure": but this form of statement does not commend itself so highly as the preceding.

FIG. 93. Drumlins in Ireland, after Kinahan and Close. (Davis.)

* "General Glaciation of Iar-Connaught," Dublin, 1872.

† "Transactions of the Geological Society of Glasgow," vol. iii, 1867, p. 61.

In this country, Professor C. H. Hitchcock and Mr. Warren Upham, while engaged on the geological survey of New Hampshire, were the first to discover the parallelism between glacial motion and the axes of drumlins in 1875. They concluded that "the accumulation of these hills and slopes seems to have been by slow and long-continued addition of material to their surface, the mass remaining nearly stationary from the beginning of its deposition. Obviously this was the case with the lenticular slopes gathered behind the shelter of higher ledgy hills or upon their opposite sides." * A little later Upham wrote, "Although we do not discover the cause of the peculiar distribution of these hills, it seems quite certain that they were accumulated and molded in their lenticular form beneath the ice." † President Chamberlin's observations led him to a similar conclusion: "The drift presents some peculiar tendencies to aggregation. . . . A special tendency is observed over certain considerable areas lying not far from the Kettle Moraine to accumulate in mammillary or elliptical or elongated hills of smooth-flowing outline." ‡ And again, after repeating this opinion, it is suggested that "a deeply hidden boss of rock is usually and perhaps universally the determining cause of these peculiar accumulations." #

In reviewing these explanations and the observations on which they are based, together with such evidence as my own studies have discovered, the conclusion that drumlins should be compared to sand-banks in rivers appears the most satisfactory yet advanced. They seem to be masses of unstratified drift slowly and locally accumulated under the irregularly moving ice-sheet where more material was brought than could be carried away. The evidence for the subglacial growth of drumlins may be summarized as follows: The scratched stones in the mass of bowlder-clay show a differential motion of its several parts as they were scraped and rubbed along from a generally northern source and gradually accumulated where

* "Geology of New Hampshire," vol. iii, p. 308.

† "Proceedings of the Boston Society of Natural History," vol. xx, p. 223.

‡ "Geology of Wisconsin," vol. i, 1883, p. 283.

"Third Annual Report of the United States Geological Survey," 1883, p. 303.

now found. The compactness of the mass suggests an origin under heavy pressure; the attitude of the hills demonstrates a close dependence on the motion of the ice-sheet; the superposition of kames on their flanks proves that their present form was essentially completed when they were uncovered by the ice-sheet, and the small change of form in the kames shows that the drumlins also can have suffered very little from postglacial erosion; the faint channeling of their smooth slopes by rain measures the small amount of denudation that they have suffered since they were made. It must therefore be concluded that they were finished closely as we now see them when the ice melted away, and hence they were of subglacial construction.

The supposed manner of accumulation of drumlins may be briefly sketched. It is well known that a stream of running water will at one point carry along silt and sand that must be dropped a little farther on where the current slackens, and the bank thus begun grows slowly in a form of least resistance, attaining a maximum size when its increase of volume has so far diminished the cross-section of the stream and consequently increased the velocity that no more detritus can be dropped there; but even then one end may be worn away while the other grows, the adjustment of velocity to channel is not permanent. The motion of a glacial sheet has been justly compared to that of a broad river. The comparison may be extended so as to liken the active head-waters of a stream to the presumably fast-moving part of the ice-sheet near its source or center of dispersion where the greatest erosion generally takes place. The delta of a river corresponds to the thinner and slower-moving marginal area of an ice-sheet, where drift brought from elsewhere is quietly and evenly deposited, as in Minnesota, and where erosion is relatively weak. A still further agreement is discovered in comparing the drumlins and sand-banks found in the middle course of the molten and solid streams as suggested by the several authors quoted above. In view of the irregularity of the surface on which the ice-sheet moved and of the greater weakness of some rocks than others, we must suppose an irregular velocity in the motion of the ice and an unequal distribution of the rubbish beneath it. If the

faster motion at one place cause an excess of erosion there, the slower motion at another place may bring about an excess of deposition. This difference of action is known to prevail between the central and marginal parts of glaciated areas, and the local accumulation of drumlins in an intermediate region gives a smaller example of these two parts played by the ice. If the causes of the irregular motion of the ice lie in the general form of the country, the location of faster and slower currents will be relatively permanent; the districts of faster currents would be found where the greatest volume of ice is allowed to pass, and some of the points of retardation may be the seats of long-continued drumlin-growth. The drumlins thus begun will depend less upon the immediately local form of the ground than on the topography of a more considerable district, and hence we need not suppose every drumlin to have begun its growth upon a knob of rock, although the beginning of many hills may have been thus determined. Once begun, the drumlins will go on increasing in size as long as deposition exceeds erosion, always maintaining an arched form of least resistance until a maximum size is reached or until the ice melts away; and in their growth they will approach the form to which rough, rocky hills would be reduced by the reverse process of erosion if time enough were allowed. Under unending glaciation the whole surface must be rubbed down smooth.*

As these theories relating to the formation of drumlins involve the general principles upon which we are to explain other evidences of the varying degrees of erosion effected by moving ice, we may as well introduce here, as anywhere, Mr. Geikie's general reply to the objections urged from the supposed nature of the case: †

Our ice-sheet flowed, we can not doubt, with a differential motion: it must have moved faster in some places than in others. In steep valleys and over a hilly country its course

* "American Journal of Science," vol. cxxviii, pp. 413–416.

† "The Preservation of Deposits of Incoherent Materials under Till or Bowlder Clay," in the "Geological Magazine," February, 1878, pp. 2, 3, 6, 7.

would often be comparatively rapid, but very irregular—lagging here, flowing quickly there—while in wide, open valleys that sloped gently to the sea, such, for example, as those of the Forth and the Tweed, the whole body of the ice would flow with a slower and more equable motion. As the ice-sheet approached its termination, more especially if that terminus chanced to be upon a broad and comparatively flat region, like East Anglia, the erosive power of the ice would become weaker and weaker, for two reasons: first, because of its gradual attenuation; and, secondly, because of its constantly diminishing motion. These, in a few words, are the varying effects which one might *a priori* infer would be most likely to accompany the action of a great ice-sheet. And an examination of the glacial phenomena of this and other countries shows that the actual results are just as we might have anticipated, had it been previously revealed to us that a large part of our hemisphere was, at a comparatively recent date, almost entirely smothered in ice. In places where, from the nature of the ground, we should look for traces of great glacial erosion, we find rock-basins; in broken, hilly tracts, where the ice-flow must have been comparatively rapid but irregular, and the glaciation severe, we meet with *roches moutonnées* in abundance, but with very little till; in the open Lowlands and in the broad valleys where the ice-sheet would advance with diminished but more equable motion, we come upon wide-spread and often deep glacial deposits, and now and again with interglacial beds; while over regions where the gradually decreasing ice-sheet crawled slowly to its termination, we discover considerable accumulations of till, often resting upon apparently undisturbed beds of gravel, sand, and clay.

The distribution of interglacial deposits, therefore, is really in itself a proof that they have been overridden by ice. When they occur in highly glaciated regions, it is only as mere patches, which, occupying sheltered places, have been preserved from utter destruction. In the opener, low grounds they are found in greater force, although in such places they almost invariably afford more or less strong evidence of having been subjected to much erosion and crumpling. But the farther we recede from the principal centers of glaciation, and the

nearer we approach the extreme limits reached by the ice-sheets, the more extensive and the less disturbed do interglacial deposits become. In a word, they occur in best preservation where the erosive power of the ice was weakest; they are entirely wanting where we have every reason to believe that the grinding force was strongest. . . .

It is needless to refer one to the petty glaciers of the Alps and Norway to prove that glacier-ice can not both erode its bed and accumulate *débris* upon that bed at one and the same time. A mountain-valley glacier is one thing—a glacier extending far into the low grounds beyond the mountains, and, it may be, coalescing with similar extensive ice-flows, is another and very different thing. No considerable deposit could possibly gather below Alpine glaciers like those of Switzerland and Norway; but underneath glaciers of the kind that invaded the low grounds of Piedmont and Lombardy we know that thick deposits of tough bowlder-clay, crammed with scratched stones, did accumulate; and not only so, but that *these glaciers flowed over incoherent deposits of sand and clay containing marine shells of late Tertiary age, without entirely obliterating them.* The deposits referred to occur now as little patches within the area bounded by the great terminal moraines.

As physicists themselves are not yet quite agreed upon the subject of glacier motion, it is not incumbent upon the geologist to explain the precise mode in which a thick mass of ice can creep over the surface of incoherent beds without entirely demolishing them. It is enough for him to show how the remarkable distribution of the interglacial beds, and the various phenomena presented by these deposits, indicate that ice *has* overflowed them. It is useless, therefore, to tell him that the thing is impossible. The statement has been made more than once that an ice-sheet several thousand feet thick is a physical impossibility; but, unfortunately for this dictum, the geological facts have demonstrated that such massive ice-sheets have really existed, and there appears to be one even now covering up the Antarctic Continent. We used also to be told, not so many years ago, that the abysses of ocean must be void of life for various reasons, among which one was that the

pressure of the water would be too great for any living thing to endure. Yet many delicate organisms have been dredged up from depths at which the pressure must certainly be no trifle. Now, there seems to be just as little difficulty in believing that these organisms existed in a perfect state at the bottom of the ocean, as that shells imbedded in clay would remain unbroken underneath the pressure of a superincumbent ice-sheet of equal or greater weight. If the ice were in motion, the clay with its included shells might be plowed out bodily, or be merely crumpled and contorted; or it might be ridden over with little or no disturbance; or, on the other hand, it might become involved with subglacial *débris*, and be kneaded up and rolled forward—the shells in this case being broken, crushed, and striated, just as we find that the shells in certain areas of till have been. The fate of the fossiliferous beds would, in short, be determined by the rate of flow and degree of pressure exerted by the superincumbent *quasi*-viscous body—the motion of which would be largely controlled by the physical features of the ground across which it crept.

CHAPTER XII.

PREGLACIAL DRAINAGE.

One of the most marked effects of the Glacial period was its influence upon drainage systems. The changes produced in numerous river-courses of North America by the irregular deposits of till and modified drift, as well as by the existence of temporary barriers of ice during the continuance of the continental ice-sheet, are subjects of unfailing interest to the student of physical geography, and are also of great practical significance in their relation to the economic and hygienic interests of the country.

As compared with preglacial time, that which has elapsed since the close of the Ice age is admitted by all to be very short. Consequently, post-glacial erosion is much less than preglacial erosion. Before the advent of the continental ice-sheet, all the great valleys of North America had been sculptured by preglacial streams.* The effects are still to be seen even where extensive deposits of the Glacial period have partially obliterated them. The sedimentary rocks, occupying the basin of the Mississippi, and filling it with strata thousands of feet in depth, serve as one index of the extent of preglacial erosion; for all the material of this class of rocks has been ground up and transported by water. Coming down from the neighborhood of the White Mountains, the Adirondacks, and the Archæan highlands of Canada, sediment-laden streams have, from the very earliest geological ages, been engaged in wearing away the hills, scooping

* See Chapter X.

out the valleys, and silting up the sea. The Alleghany Mountains were at one time the bed of the ocean upon which this sediment was deposited. The sandstones, shales, and conglomerates of the coal-measures attest the activity of the forces of that early period. The tops of the mountains in southern New York and northern and eastern Pennsylvania are covered with subcarboniferous conglomerates of almost incredible depth and extent, consisting largely of well-rounded quartz pebbles, of all sizes up to two or three inches in diameter. These are water-worn, and must have been rolled along by impetuous currents from far-distant regions. Thus the tributaries of the Mississippi are, at the present time, bringing into its valley similar deposits from the mountain plateaus on either side. But no sooner did the convulsive forces of the earth begin to lift this great, stratified ocean-bed of the Appalachian region above the water, than it too became the subject of erosion, and began to furnish material for newer deposits farther to the south and west.

The Ohio River and its tributaries furnish a good example of the extent of preglacial erosion. The traveler is impressed with the gorge in the Niagara River below the falls, as showing the force of running water when concentrated in a single line of drainage. The gorge of the Niagara, however, is only about seven miles long, a thousand feet wide, and three hundred feet deep. This, as will appear later,* is one of the best measures of post-glacial erosion. But the Ohio River, containing a far less volume of water, has worn a much larger and deeper trough more than a thousand miles in length. The character of the trough of the Ohio and its tributaries is readily discerned, even by the passing observer. The strata on the opposite sides are horizontal, and match each other like the ends of a plank that has been sawed asunder. The alternate layers of conglomerate, coal, shale, and sandstone upon the one side of the river correspond to simi-

* See Chapter XX.

lar layers on the other side. The width of the gap cut by the stream averages about a mile, with enlargements wherever a tributary comes in from either side. The tributaries, also, occupy corresponding narrow valleys of erosion, extending even to their very sources in the mountains. The nature of the cause producing these narrow troughs, and its long-continued operation in every one of these tributaries of the Ohio, are not difficult to see. They have all been formed by running water. The Tennessee, the Cumberland, the Kentucky, the Wabash, the Miami, the Licking, the Scioto, the Big Sandy, the Kanawha, the Hocking, the Muskingum, the Big Beaver, the Monongahela, and the Alleghany, together with their tributaries, all show the vast amount of water-erosion along these lines of preglacial drainage.

But even these do not, in their present condition, reveal the whole extent of the effect of the constant and long-continued erosive forces of preglacial times. The ancient bed of the Ohio River was certainly one hundred and fifty feet deeper than that over which it now flows, it having been filled with glacial *débris* to its present level. According to Professor Newberry—

At the junction of the Anderson with the Ohio, in Indiana, a well was sunk ninety-four feet below the level of the Ohio before rock was found. In the valley of Mill Creek, in the suburbs of Cincinnati, gravel and sand were penetrated to the depth of one hundred and twenty feet below the stream before reaching rock. On the margin of the Ohio, at Cincinnati, gravel and sand have been found to extend to a depth of over one hundred feet below low-water mark, and the bottom of the trough has not been reached. The falls of the Ohio, formed by a rocky barrier across the stream, though at first sight seeming to disprove the theory of a deep continuous channel, really affords no argument against it; for here, as in many other instances, the present river does not follow accurately the line of the old channel, but runs along one side of it. At the Louisville falls, the Ohio flows over a rocky point which projects from the north side into the old valley, while the deep

channel passes on the south side, under the lowlands on which the city of Louisville is built.

The tributaries of the Ohio exhibit the same phenomena. At New Philadelphia, Tuscarawas county, the borings for salt-wells show that the Tuscarawas is running one hundred and seventy five feet above its ancient bed. The Beaver, at the junction of the Mahoning and Chenango, is flowing one hundred and fifty feet above the bottom of its old trough, as is demonstrated by a large number of oil-wells bored in the vicinity. Oil Creek is shown by the same proofs to run from seventy-five to one hundred feet above its old channel, and that channel had sometimes vertical and even overhanging walls.*

Additional particulars of much interest concerning buried channels in the Ohio are given by other geologists. For example, Professor Joseph F. James presents cogent reasons for believing that the northward bend of the Ohio River, now culminating at Cincinnati, continued still farther north previous to the Glacial period, and extended through Mill Creek up to join the valley of the Great Miami at Hamilton. He supposes that the main stream then ran north of the city through the valley in which Madisonville is situated. The evidence of this is, that below Cincinnati, a short distance, the present river flows, beyond all doubt, over bedded rock between Price Hill and Ludlow, Ky.; while borings show that up Mill Creek several miles the bed-rock lies certainly thirty-four feet below low-water mark, while at Hamilton, twenty-five miles north of Cincinnati, the preglacial valley is found to be filled up to a depth of more than two hundred feet, and the bed rock lies ninety-one feet below low-water mark in the Ohio at Cincinnati.†

Mr. M. C. Read, among other numerous references to buried channels, describes one in Knox county, east of Gambier, in the valley now occupied by Owl Creek, where the

* "Geological Survey of Ohio," vol. ii, pp. 13, 14.

† "Journal of the Cincinnati Society of Natural History," July to October, 1888, pp. 96-101, and a subsequent personal communication.

bed-rock lies eighty-two feet below the bottom of the present stream. West of Mount Liberty, in the same county, the drift conceals an old gorge two hundred and eighty-five feet deep.* Mr. P. Max Foshay, in a paper before the American Association for the Advancement of Science, in 1888, gives many reasons for supposing that Beaver Creek, which now empties into the Ohio, was connected by a buried channel with Grand River, emptying into Lake Erie at Painesville, and hence that a still larger portion of the upper Ohio drainage than was supposed by Mr. Carll passed into the St. Lawrence Valley. This suggestion was first made by Professor Spencer and indicated on one of his maps over twenty years ago.

Every day is demonstrating that the present level appearance of the surface of the northwestern portion of Ohio is due to the extensive deposits of the Glacial period, whose effect has not been so much to make the hills low as to exalt the valleys. Professor Orton long ago called attention to the numerous buried channels near Springfield in Clarke county, one of which is occupied by the New York, Pennsylvania, and Ohio Railroad.‡ The extensive explorations for stores of gas and oil now in progress in the western part of Ohio and the eastern part of Indiana are bringing to light buried channels in most unexpected places, that at St. Paris, Champaign county, being more than five hundred feet deep. This is an extreme case, but it illustrates what a network of preglacial gorges have been plastered up by the ice-movement which passed over the region. The country resembles, on a large scale, a checked and worm-eaten plank which a carpenter has filled with putty.

One of the first effects of this filling up of the preglacial channels has been so to change the lines of superficial drainage, in a great multitude of instances, that the streams are now made to run over rocky beds at levels far higher than

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* "Geological Survey of Ohio," vol. iii, pp. 325-347.
‡ "Geological Survey of Ohio," vol. i, pp. 450-480.

they had formerly occupied. Thus it is that the glaciated region became again a region of waterfalls. Almost every stream entering Lake Erie from the south exhibits waterfalls produced in this manner. In Minnesota the falls of St. Anthony, at Minneapolis, and of Minnehaha, a few miles below, were thus produced, and, so, are post-glacial in their origin, the ancient channels having been filled with glacial *débris.*

The falls of Niagara are due to the same cause. The preglacial outlet to Lake Erie was dammed up and buried by glacial *débris*, so that the water was compelled to seek another channel. Before the Ice age there was no Niagara River, and Lake Erie is, in fact, but a glacial mill-pond. The falls of the Genesee at Rochester are also clearly due to the same cause. The preglacial valley in the Genesee is now deeply buried. "Between Mount Morris and Rochester the river follows its preglacial valley, but flows for much of this distance on an alluvial plain that closely resembles the filling of an old lake; above and below the limits named the river has cut a new channel since glacial times, giving some of the best natural sections in the State, and its old course is choked with drift." *

The falls of the Mohawk at Cohoes, also, doubtless indicate the existence of a deeply buried channel somewhere in the vicinity, connecting, as we shall see a little later, the basin of Lake Ontario with the Hudson.

The evidence that the preglacial outlet of Lake Erie was much lower than its present outlet, lies in the fact that several rivers now entering the lake from the south flow at a level two hundred feet above that formerly occupied by them, since that distance has been penetrated beneath their present bottom before reaching rock. From various borings at Cleveland it appears that rock bottom at the mouth of the Cuyahoga lies more than 500 feet below the level of the lake, and is at a depth of at least 200 feet twenty miles in land.

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* See Professor W. M. Davis, in the "Proceedings of the Boston Society of Natural History," vol. xxi, p. 359.

Thus, since the elevation of Lake Erie is only 373 feet above tide, the rock bottom of the Cuyahoga River, though 700 miles inland, is now nearly at sea level. Newberry also discovered that Grand and Rocky rivers flow over deeply buried channels. In the case of Rocky River, Dr. D. T. Gould has

FIG. 94.—Section across the valley of the Cuyahoga River, twenty miles above its mouth (Claypole.)

traced the buried channel southward for a distance of nearly thirty miles, or into its upper waters in Medina county. This he has done by collecting the record of wells along the route, and by noting various places where the present stream crosses the old bed, passing out of rocky banks for a short distance, and running through clay banks and over a clay bottom to enter its new channel again between rocky walls.

Professor Spencer has also shown, with great probability, what was the preglacial line of drainage through which the waters, both of Lake Huron and of Lake Erie, flowed to enter Lake Ontario on their way to the sea. The line, as he first thought, passes out of Lake Huron through the valley of the Au Sable, crossing the Thomas River near London, in Canada, and entering the basin of Lake Erie a little east of Port Stanley. Thence, after passing around Long Point and Island, it bends northward through the valley of Grand River, and enters Lake Ontario at its extreme western point.* From later information, furnished me by letter, it appears that Professor Spencer is inclined now to make the connection between Lake Huron and Lake Ontario direct, passing through Georgian Bay, and reaching Ontario in the vicinity of Toron-

* "Second Geological Survey of Pennsylvania," Q^4, pp. 357–406.

to, as shown in his accompanying map. Thence, according to Newberry, the ancient line of drainage passed through Ontario, and emerged in a stream occupying the valley of the Mohawk, to swell the current of the Hudson rather than that of the St. Lawrence.*

The facts concerning this line of preglacial drainage had been thus succinctly stated by Professor Newberry in an earlier paper:

Some of the streams draining into the basin of Lake Ontario in former times cut their channels below the present ocean-level. All the salt-wells of Syracuse are sunk in one of these, which is filled with gravel and sand saturated with brine issuing from the salina group that forms its walls. The rock-bottom of this old river-bed was reached in some of these wells at a depth of fifty feet below the present level of tide-water.

The valley of the Mohawk is a very deep channel of erosion, now half filled, which must have been traversed by a large stream flowing eastward at a level below that of the present ocean; and everything indicates that this was the ancient outlet of the basin of the Great Lakes.

The channel of the Hudson is apparently the only possible continuation of this long line of drainage. As has been remarked, it is of great and yet unknown depth. The clay by which it is partially filled has been penetrated to a depth of about one hundred feet along its margins. How deep it is in the middle portion can only be conjectured; but Hell-Gate Channel, which has been kept comparatively free by the force of the tides, is in places known to be nearly two hundred feet deep; and, since this is a channel of erosion formed by a stream draining into the Hudson, the ancient bed of the Hudson must be still lower.†

The silting up of these preglacial outlets has enlarged Lakes Ontario and Huron far beyond their previous limits, and wholly created Lake Erie. Lakes Michigan and Superior

* Paper read before the American Philosophical Society, November 4, 1881, p. 93.

† "Popular Science Monthly," vol. xiii, p. 16.

were likewise greatly enlarged by the damming up of outlets which formerly conducted their waters southward into the Mississippi. These barriers also turned the surplus waters of those inland seas toward the east. The outlet of Lake Superior through the rapids of the Sault Ste. Marie is caused by the increased depths of the glacial deposits to the west across the narrow isthmus separating it from Lake Michigan, where, doubtless, a ship-canal could be cut between these two lakes without encountering any rocks at all. From the southern end of Lake Michigan, also, a deeply-buried preglacial channel is believed to run southwest, through Kankakee, Livingston, and MacLean counties, toward the Mississippi.

Professor Newberry's theory of the eastward preglacial drainage from the region of Lake Ontario meets with insuperable difficulties, notwithstanding the apparent support it would receive from the startling facts recently brought to light concerning the depth of the preglacial trough of the Hudson River, where the engineers sounding for a foundation for a conduit to convey water from the Catskill region to New York City in 1906, found that a short distance above West Point the rock bottom of Hudson River was 487 feet below the present bottom. The depth of the buried channel between New York and Newark is not certainly known, but the numerous railroad tunnels under the river are uniformly through unconsolidated sedimentary deposits, and in case of the Pennsylvania road abutments are sunk to a considerable depth in the mud to support the tunnel, as if it were a bridge. Outside the harbor of the city this preglacial outlet has been traced by the sounding line of the Coast Survey for a distance of a hundred miles, to the edge of the deep water of the Atlantic. Over a considerable portion of this distance it has a width of more than a mile and is 2,000 feet deep. These facts concerning the Hudson, brought to light since Professor Newberry's death would have greatly strengthened his argument. There is, however, one fatal objection to his con-

clusion. At Little Falls, a spur of archaean rocks projects from the Adirondack Mountains and effectually separates the preglacial drainage of the western part of the state from that of the eastern. Professor Newberry had supposed that there was room for a deep preglacial channel to lead around this obstruction, but fuller examination shows that this could not have been the case. The upper part of the St. Lawrence is also crossed by continuous strata of archaean rocks, showing that there was no preglacial channel permitting drainage in that direction.

To a superficial observer it would seem that the way was equally closed into the Mississippi Valley. For it would appear in the highest degree unlikely that the drainage of Lake Ontario, whose bottom is now 507 feet below tide level, could ever have found a way across the intervening highlands which separate it from the Mississippi Valley, the lowest place of which (at Chicago) is more than 600 feet above tide level. But our conception of the depth of the glacial deposits over this intervening area, and of the preglacial gorges that have been filled by them has been enormously enlarged by every fresh investigation of the region.

The course of preglacial drainage in the upper basin of the Allegheny River is worthy of more particular mention. Mr. Carll, of the Pennsylvania Geological Survey, has conclusively shown that previous to the Glacial period the drainage of the valley of the upper Allegheny north of the neighborhood of Tidioute, in Warren county, instead of passing southward, as now, was collected into one great stream flowing northward through the region of Cassadaga Lake to enter the Lake Erie basin at Dunkirk, N. Y. The proof of this is that between Tidioute and Warren the present Allegheny is shallow, and flows over a rocky basin; but from Warren northward, along the valley of the Conewango, the bottom of the old trough lies at a considerably lower level, and slopes to the north. Borings show that in thirteen miles the slope of

the preglacial floor of Conewango Creek to the north is 136 feet. The actual height above tide of the old valley floor at Fentonville, where the Conewango crosses the New York line, is only 964 feet; while that of the ancient rocky floor of the Allegheny at Great Bend, a few miles south of Warren, was 1,170 feet. Again, going nearer the head waters of the Allegheny, in the neighborhood of Salamanca, it is found that the ancient floor of the Allegheny is, at Carrollton, seventy feet lower than the ancient bed of the present stream at Great Bend, about sixty miles to the south; while at Cole's Spring, in the neighborhood of Steamburg, Cattaraugus County, N. Y., there has been an accumulation of 315 feet of drift in a preglacial valley whose rocky floor is 155 feet below the ancient rocky floor at Great Bend. There must, therefore, of necessity have been some other outlet than the present for the waters collecting in the drainage-basin to the north of Great Bend.

While there are numerous superficial indications of buried channels running toward Lake Erie in this region, direct exploration has not been made absolutely to demonstrate the theories. But, if resorted to, we know, from the facts just stated, that the line of some such drainage valley must be discovered. In the opinion of Mr. Carll, Chautauqua Lake did not flow directly to the north, but, passing through a channel nearly coincident with that now occupied by it, joined the northerly flowing stream a few miles northeast from Jamestown.* It is probable, however, that Chautauqua did not then exist as a lake, since the length of preglacial time would have permitted its outlet to wear a continuous channel of great depth corresponding to that known to have existed in the Conewango and upper Allegheny.

Farther west as already shown, the Middle Allegheny appears to have followed a channel leading past Meadville through French Creek to the Lake in the vicinity of Erie, Pa., while the drainage of the Monongahela was clearly northward through Beaver Creek and the Mahoning and Grand

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* "Second Geological Survey of Pennsylvania," iii.

River valleys to Lake Erie, a little west of Ashtabula. This was demonstrated by Mr. Hice, who discovered pot-holes on the rock terraces of Beaver Creek all pointing northward. This line of preglacial drainage of the Upper Ohio has been chosen by the engineers as the best route for the canal to connect Lake Erie with the Ohio Valley. The portion of the Upper Ohio following this line in preglacial times is that above Martinsville, where there is a well marked narrow place in the gorge indicating a preglacial col between two systems of drainage. The water, being thrown over this by the glacial dam, speedily eroded a channel such that upon the melting of the ice the water continued to flow in that direction.

According to the investigations of Professors Tight and Bownocker, it would seem, also, that the drainage of the Middle Ohio was through buried channels leading to the northwest, along a line nearly coinciding with the valley of the Scioto. As will be detailed more fully in another chapter (p. 379, seq.) the Middle Ohio, below Martinsville flowed southwest as far as Huntington, West Virginia, where it was joined by the Kanawha, a still larger stream coming down from the Appalachian Mountains through the deserted channel of Teazes Valley. At Huntington the united current turned northward to the vicinity of Portsmouth at the mouth of the present Scioto, where it was met by a shorter stream flowing eastward from a col in the Ohio at Manchester. Ten miles above Portsmouth, at Wheelersburgh the Little Scioto enters the Ohio after having flowed for many miles through a broad abandoned channel, which near the village of California inosculates with another running northwestward into the Scioto at Waverly. It is the opinion of Mr. Leverett, and of Professors Tight and Bownocker, that the Kanawha drainage in preglacial times took this course, and then proceeded in a northward direction through the buried channel of the Upper Scioto.

A little below Columbus this stream was joined by one

emerging from the Tuscarawas Valley through a clearly marked buried channel leading from one valley to the other at Newark. At the present time the Tuscarawas drainage turns a right angle at Dresden and flowing south to Zanesville is joined by the Licking River coming from the northwest, and both flow southward through a narrow, and clearly post-glacial valley to the Ohio at Marietta.

The whole country north of Columbus is so deeply covered with glacial drift that it is impossible to trace the preglacial drainage except through the aid of borings which have been made in search of artesian water, or of gas and oil. But these have revealed so many deep cañons, in some cases more than

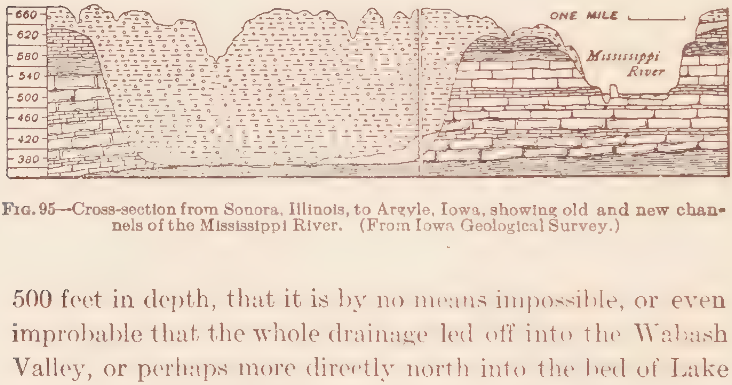

FIG. 95—Cross-section from Sonora, Illinois, to Argyle, Iowa, showing old and new channels of the Mississippi River. (From Iowa Geological Survey.)

500 feet in depth, that it is by no means impossible, or even improbable that the whole drainage led off into the Wabash Valley, or perhaps more directly north into the bed of Lake Erie, and so around into the Wabash or Illinois.

The preglacial drainage of the Lower Ohio is equally interesting. As already shown, and as appears graphically in the map on p. 643, the Licking River of Kentucky continued north from Cincinnati through the valley of Mill Creek, having been joined at Ivorydale by that portion of the preglacial Ohio which came from the col below the mouth of the Scioto. This united stream, after reaching Hamilton, probably turned southward through the channel of the Great Miami, which is much broader than that of the Ohio just below Cincinnati. Below Lawrenceville, Indiana, there has been little change in

the course of the river since preglacial times except in the vicinity of Louisville, Kentucky, where it now flows over a rocky barrier constituting the Falls which obstruct navigation at this point. There is, however, a deeply buried channel south of Louisville filled with the coarser silt bought down by glacial floods from the melting ice which reached and crossed the river for some distance above.

Coming to the Mississippi River two preglacial channels are of special interest. One lies just west of Minneapolis, following a wide shallow depression dotted with small lakes and entering the valley of the Minnesota a short distance above Fort Snelling, where the present Mississippi joins the valley. This preglacial gorge is now filled with glacial *débris* to a depth of 200 feet or more. The present Mississippi after plunging over the Falls of St. Anthony occupies a narrow rocky gorge, which it has worn since glacial times, to its junction with the main valley.

A similar broad, deep preglacial valley channel of the Mississippi now filled with glacial *débris* is found west of Keokuk, Iowa. This became so completely filled with till that the river was forced to seek its present channel, which passes over rocky rapids at Keokuk, compelling the government to construct there a canal with locks for the sake of navigation. (See Fig. 95).

In Professor I. C. White's report upon Pike and Monroe counties, Pennsylvania,† he gives an account of no less than twenty-three channels which have been buried by glacial *débris*. Among these that of the Wallenpaupack Creek is the most striking. At present this creek empties into the Lackawaxen at Paupack Falls, where it descends 260 feet in a mile. But on ascending the creek two or three miles, to the vicinity of Tafton, the course of a preglacial valley can be easily recognized, leading into Kimball's Run, and joining the Lackawaxen at Kimball's Station. This channel is

† Ibid, G⁶, pp. 52-63.

now buried to a depth of 300 feet for a distance of many miles.

R. W. Ells calls attention, also, to the numerous buried channels* in the Eastern Townships, in the province of Quebec, in the vicinity of Lake Memphremagog. These are, to a considerable extent, explored at the present time for the sake of the gold found in them.

These are but a few of the innumerable facts indicating that before the great Ice Age not only the Ohio, but nearly all the streams of the eastern United States, occupied deeper channels than they now do. There were then probably no Great Lakes, and few if any waterfalls, as there are now no lakes and waterfalls south of the glaciated region. All the rivers had cut their channels down so low that they drained to the bottom any lakes that may have once existed.

* "Annual Report of the Geological and Natural History Survey of Canada," vol. ii, 1866, p. 49, J.

CHAPTER XIII.

DRAINAGE OF THE GLACIAL PERIOD.

During the continuance of the Ice age, an extraordinary factor was in the field to modify the lines of drainage, and to give to them both a direction and a character such as they never had had at any other time. Throughout the whole extent of the Glacial period the ice itself was a most important barrier, deflecting the course of the streams, and, at the same time, was a cause of irregularity in the volume of water such as is altogether unique in the history of the world. The vast mass of frozen water then stored up at a high level was an immense reservoir of force, ready, on proper conditions, to descend in torrents through any channel which was opened before it.

As the ice of the Glacial period advanced southward from the Laurentian highlands, it reversed the currents of all the great rivers which flowed to the north. One of the first and most remarkable effects of this advance must have been the damming up of Nelson River, so as to cause the surplus water—ordinarily flowing through Hudson Bay into the North Atlantic—to pour over into the head-waters of the Mississippi and so into the Gulf of Mexico. Thus, from the beginning of the Glacial period to its close, the Mississippi River must have been the channel through which was carried off the waste water from the larger part of the Dominion of Canada as well as from the central portion of the United States. A little later, also, the drainage of the Great Lake region must have been obstructed toward the northeast and east; for, long before the eastern lobe of the glacier had

reached the latitude of New York city, the valleys of the St. Lawrence and of the Mohawk must have been closed up by ice so as to reverse their lines of drainage. The waters of Lakes Superior and Michigan must then have flowed into the Mississippi River along the lines of the Fox, Wisconsin, and Illinois Rivers, while those of Lakes Huron and Erie poured into the Ohio River, at first down the Wabash, then, a little later, when the extension of the central lobe of ice cut off the western outlet of Lake Erie, over the lowest places in the water-shed into the valleys of the Scioto, the Muskingum, and Beaver Rivers; at the same time, every northern tributary of the Alleghany was a glacial flood.

But the scenes to have been witnessed during the advance of the ice-sheet are as nothing compared with those which must have occurred during its retreat. Even now, every spring has its freshets, when the combined action of ice and water produces floods unparalleled at other seasons of the year. If this is the case upon the melting of the small amount of snow which annually accumulates in our present winters, the floods at the breaking up of the Glacial period itself must have been inconceivably great. With every recurring spring we now look in the telegraphic summary for thrilling accounts of ice-gorges formed in the St. Lawrence, the Delaware, the Susquehanna, and the Missouri River. By reason of these gorges, and their accompanying destructive floods, Port Jervis, on the Delaware, and Mandan, on the Missouri, have become familiar names. Reasoning from the nature of the case, what, then, must have been the scenes during the last stages of the great Ice age, when, through the months of July, August, and September, warm southerly winds and a glowing sun were combining to dissolve, with utmost rapidity, the vast masses of ice which still lingered in the country! The channels were then compelled to carry off not only the annual precipitation, and the torrents of an occasional cloud-burst, but the stored-up precipitation which had been accumulating as glacial ice for thousands of years.

Nor is this altogether theoretical. Though we have no

telegraph to span the distances of time separating us from those events, we have come into possession of signs as intelligible as the lines and dots of the Morse alphabet, and even more trustworthy. These floods along the lines of glacial drainage have left their marks, and their direction and extent can be traced almost as readily as in the case of the present streams.

Ascending the channel of the Mississippi above its junction with the Ohio, one enters a region where it is bordered on each side by rocky bluffs, and finds himself in a valley of erosion whose main features were determined in preglacial times. Above Grand Tower, in southern Illinois, and as far north as St. Louis (a distance of about one hundred and fifty miles), the extreme margin of glacial deposits rests upon the east side of the river, and an unglaciated region is upon the west; the width of the eroded valley being from five to ten miles, and its depth several hundred feet. Above St. Louis the valley gradually narrows, though it is still from two to eight miles in width, and about the same depth as below the city. At various places, along the sides of this eroded valley, the observer will find gravel terraces one or two hundred feet above the present flood-plain. These terraces are, in fact, the high-water mark of the closing floods of the Ice age.

But the culmination of interest is reached on coming to the present junction of the Minnesota and Mississippi Rivers near St. Paul. From Fort Snelling, just above St. Paul, northward, the present Mississippi River is a comparatively recent stream, occupying a post-glacial bed. The true extension of the trough of the Mississippi follows up the Minnesota River. The gorge of the Mississippi, leading from Fort Snelling up to Minneapolis, is scarcely a quarter of a mile in width, and is about two hundred and fifty feet in depth; while the trough of the Minnesota is from one to four miles in width, and its rocky bottom is more than one hundred and fifty feet lower than the present bed of the stream. In the bottom of this broad valley, for a distance of two hundred and fifty miles, the Minnesota River wanders about from

side to side as a very insignificant thing, entirely out of proportion to the valley which it occupies. Nor does the Minnesota River have its sources in the highlands, like the Mississippi. Its head is in Big Stone Lake, in the midst of this eroded trough, and but a few miles south of Lake Traverse — the head of the Red River of the North—also in the same trough and on the same absolute level. The water from Lake Traverse sometimes flows into the other lake. In short, the troughs of the Minnesota and the Red River of the North are one and continuous, and the depression joining them, known as Brown's Valley, is to the glacialist one of the most interesting spots on the continent. The following is Mr. Upham's description:

Lakes Traverse and Big Stone are from one to one and a half mile wide, mainly occupying the entire area between the bases of the bluffs, which rise about one hundred and twenty-five feet above them. Lake Traverse is fifteen miles long; it is mostly less than ten feet deep, and its greatest depth probably does not reach twenty feet. Big Stone Lake is twenty-six miles long, and its greatest depth is reported to be from fifteen to thirty feet. The portion of the channel between these lakes is widely known as Brown's Valley. As we stand upon the bluffs here, looking down upon these long and narrow lakes in their trough-like valley, which extends across the five miles between them, where the basins of Hudson Bay and the Gulf of Mexico are now divided, we have nearly the picture that was presented when the melting ice-sheet of British America was pouring its floods along this hollow. Then the entire extent of the valley was doubtless filled every summer by a river which covered all the present areas of flood-plain, in many places occupying as great width as these lakes.*

Among the most interesting facts concerning the drainage lines of the glacial period are those connected with the

* "Proceedings of the American Association for the Advancement of Science," vol. xxxii, 1883, pp. 216, 217. This glacial outlet through Brown's Valley and the Minnesota has been fittingly named, by Mr. Upham, River Warren, after General G. K. Warren, who first described it. See map in Chapter XXI.

advance and recession of the ice from the basin of the Great Lakes. As the advancing ice closed up the outlets leading into the St. Lawrence Valley the drainage was successively turned through Lake Champlain into the Hudson. A little later it was turned around the Adirondacks through the Mohawk River Valley into the Hudson. Later still it was turned over into the Susquehanna through the fissures now occupied by the Finger Lakes of Central New York. A still farther advance turned the vast current through the valley occupied by the Grand, Mahoning and Beaver rivers into the head-waters of the Ohio and helped in the formation of its present tortuous channel.

Meanwhile the advance of the ice farther west was producing numerous changes in the drainage of the upper lake region. At first the drainage of Lakes Erie and Huron was turned through the straits of Mackinaw into Lake Michigan and ran off through the line of the present drainage canal into the Mississippi through the Illinois River. Then, as soon as the eastern end of Lake Superior was closed up, the drainage from the western portion was through the St. Croix River at an elevation of 466 feet above the lake into the Mississippi a little below St. Paul. With the advance of the ice a little further into the southern peninsula of Michigan the channel through the Straits of Mackinaw was closed, forcing the water over a low col leading from Saginaw Bay into the head-waters of Grand River, and thence into Lake Michigan a short distance below Grand Rapids, and so again over the line of the Chicago drainage canal into the Mississippi basin.

A still further advance closed up the entire passage into Lake Michigan and turned the drainage southward from Toledo, Ohio, through the pass at Fort Wayne, Indiana, into the Wabash River and thence into the Ohio.

Of course the direct evidence of these facts is not now available, since the advancing ice has obliterated the beaches and terraces which were built up before it. But on the retreat

FIG. 96.

FIG. 97.—Cross section of the Osage trough at Tuscumbia, Mo., with a Canadian bowlder on the upper terrace above the flood plain. (See p. 321).

of the ice these lines were opened in reverse order and shore lines and abandoned channels were left for inspection for all time. These abandoned channels and the bordering high-level gravel terraces are clearly marked through the line of the St. Croix River in Wisconsin, through the line of the Chicago drainage canal, through the pass at Fort Wayne and along the whole course of the Wabash River in Indiana, and to a greater or less extent through the other passes which were occupied by the reversed glacial floods for a shorter time further east. The shore lines of the temporary glacial lakes whose levels were determined by the height of these several passes are also clearly marked around the west end of Lake Superior in the terraces above Duluth; and around the southern shore of Lake Erie where at three levels already mentioned they lead to Fort Wayne, at an elevation of 200 feet above the present level of the lake, and from Saginaw Bay at levels of 150 and 100, respectively, to the upper and the lower passes into Grand River, Michigan.

Mr. Frank Leverett discovered a most interesting displacement of a middle portion of the Mississippi River during the farthest advance of the Illinoisan ice-sheet, which pushed across the river for an average distance of from thirty to forty miles between Clinton and Keokuk. This forced the drainage along the border of the ice-sheet through a channel still clearly marked through Jackson, Clinton, Scott, Muscatine, Louisa, Des Moines, Henry, and Lee counties, a distance of about 150 miles. But on the retreat of the ice, the present channel was opened.

Gravel terraces of great prominence also mark the course of final glacial drainage through the Mohawk River in Central New York, and a shore line around the southern side of Lake Ontario is distinctly traceable from the mouth of the Niagara gorge to the col at Rome, leading from the Ontario basin into the Mohawk.

Another striking deposit of this final glacial drainage can be seen on the eastern flank of the Adirondack Mountains at Chazy, a few miles west of Plattsburgh, where there is a large and most remarkable accumulation of rolled river pebbles two or three hundred feet above the level of Lake Champlain, while there is no stream bed anywhere near this locality. The only explanation of it is (and it is entirely adequate), that this was a line of temporary drainage for the glacial floods which for a time accumulated in the upper St. Lawrence Valley and found their only passage for a while between the mountain mass of the Adirondacks and the waning ice which filled the Champlain Valley. (For an illustration from Alaska, see Plate VIII.)

From the Missouri Valley there come some of the most startling facts revealing the extent of the floods which characterized the later stages of the glacial period. The present Missouri discharges (according to Humphreys and Abbott) twenty-nine cubic miles of water annually. Yet, even so, there are frequently floods in the lower part of the valley which reach a height of thirty or forty feet above present low water mark. But at the time of the greatest extent of the ice-sheet the drainage of not far from 250,000 square miles of ice covered area found its way into the Middle Missouri. For a considerable time towards the close of the glacial epoch the ablation of this ice would, at a moderate estimate, amount to ten feet per annum over this whole contributory surface. This would furnish 500 cubic miles of additional water to be carried off through the lower portion of the river channel during each summer between April and November. An examination of the lower channel shows that at Hermon twenty-five miles below the mouth of the Osage River where it joins the Missouri the passage between rocky bluffs 300 feet high is barely two miles wide. Mathematical calculations will show that it would require ninety-six days for a current two miles wide and two hundred feet deep, flow-

PLATE VIII—Stream of water along the margin of the Malaspina Glacier, held up by the ice 2,000 or 3,000 feet above sea-level, and forming a gravel deposit along the flanks of the mountain at that elevation. (Photo by Russell.)

ing at the rate of three miles an hour, to carry off this surplus drainage of 500 cubic miles accumulating each summer.

If it should be supposed that the current would be much faster than three miles an hour, it is proper to note that from the known facts about the northerly depression of the land during the latter part of the glacial period it is extremely probable that the gradient of the stream was very much less during the time of these floods than it is now. Furthermore, the gradient of the stream was much diminished by the flooded condition of the Mississippi into which the Missouri enters. For, the glacial floods pouring into the Mississippi and Ohio were of such enormous magnitude as probably to raise the level of the Mississippi 100 feet or more, during these summers. It is not at all unreasonable, therefore, to expect to find indications of glacial floods in the Lower Missouri rising to a height of 200 feet or more.

And these we do find. In 1902, Dr. Ball of the Missouri Geological Survey found a number of large Canadian bowlders in the valley of the Osage River sixty miles above its junction with the Missouri and forty miles south of the extreme limit of the extension of glacial ice. There is no way to account for such bowlders in that position except on the supposition that they were floated in there by a backward current from the Missouri when its glacial floods, bearing floating masses of ice with Canadian bowlders upon their surface, reached a height of 200 feet. Since there was no melting ice in the valley of the Osage to increase its volume, such an eddy in the current would be sure to set up that valley and supply the cause necessary to explain what was a very puzzling problem when first propounded. Such floods also are needed in the Missouri Valley to account for the many level-topped extensive accumulations of loess (a fine river loam to be described more in detail in a later chapter) which occur at numerous points throughout the valley.

FIG. 98.—The unshaded portion shows the glaciated area; but at Tuscumbia numerous Canadian bowlders are found in the upper gravel terraces bordering the Osage river. (See fig. 97, p. 318.) These could have come into this place only by the agency of back water bearing ice floes from the glacial floods of the Missouri as described in the text.

The high level gravel terraces so constantly lining the water-courses in the Middle and Western States, and which formerly were attributed to the advance into these regions of the waters of the ocean, are readily accounted for by the action of the torrents set free by the melting of the ice during the closing years of the great Ice age. One of the striking confirmations of the glacial theory appears in the absence of terraces in the valleys of such minor streams as have their sources south of the glacial limits. For example, in Ohio the small streams in the southeastern part of the State, whose sources are outside of the glacial limits, present a marked contrast to the other streams of the State flowing south, as do also the streams flowing to the north and emptying into Lake Erie. The troughs of the Wabash, the two Miamis, the Scioto, the Hocking, and the Muskingum, with their tributaries, are all lined by gravel terraces, rising from fifty to one hundred and fifty feet above the present flood-plains, showing the enormous volume of the streams which flowed through them at the close of the period. The coarseness of the material in these terraces also bears witness to the violence of the currents. But between the mouth of the Muskingum, at Marietta, and the mouth of the Little Beaver, the streams entering the Ohio are devoid of terraces, the explanation being that their sources lie outside of the glaciated limit, so that they had access neither to the accumulations of the glacial deposits, which furnished material for the terraces, nor to the floods of water that distributed it. To the eastward, again, upon striking the streams whose drainage-basins lie within the glaciated limit, high terraces, containing northern pebbles brought from beyond the water-shed, begin again to appear, both along the margins of the streams in the glaciated area, and also through their whole course below the boundary. In the matter of terraces, likewise, the northern tributaries of the Ohio are in striking contrast with the southern.

East of the Alleghanies the same contrast appears between the streams rising within the glaciated area and those outside

Fig. 99.—Glacial terrace near the boundary of the glaciated area, on Raccoon Creek, a tributary of the Licking River, in Granville, Licking county, Ohio. Height about fifty feet.

of it. The terraces on the East Branch of the Susquehanna are much more marked than those upon the West Branch, the explanation being that the East Branch lies almost wholly within the glaciated area, while only a few of the minor tributaries of the West Branch come down from it. But wherever they do so come, as in the case of Pine, Lycoming, and Loyalsock Creeks, a limited amount of drift from the far north is distributed along their banks, and deposited at their junction with the main branch of the river. The Lehigh and the Delaware are likewise marked by high terraces containing pebbles from the far north, while the Schuylkill River, which lies just outside of the glaciated limit, has no such terraces. Thus, both by the method of agreement and of difference, we prove the connection of these terraces of the so-called "Terrace epoch" with the gorged and gravel-laden streams of the great Ice age.

Before speaking of the lines of glacial drainage farther east, it will be profitable to direct our attention to another class of closely connected facts confirming the theory of the glacial origin of these terraces. The larger part of the material contained in them is derived from the glacial deposits over the region through which the several streams flow. The hard fragments of granite, quartzite, and various metamorphic rocks from the region of Lake Superior and the Canadian highlands are eminently fitted to withstand abrasion, and can be rolled by a torrent for long distances before being ground to powder, while the softer sandstones and shales of the newer geological formations would be comminuted by the attrition of a comparatively few miles' travel. Hence it comes about that the terraces of the Middle States are composed, in a predominant measure, of material brought over the water-shed by the ice from the far north, and spread broadcast over the country, and thence collected by the streams of water and rolled along as far to the south as there was force in the current to move them, or through as great a distance as the hardness of the material of which they are composed would enable them to resist complete attrition. There is no more

interesting verification of an hypothesis anywhere to be found than that furnished for the glacial theory through the study of the character of some of these terraces at and below the glacial limit. Theoretically the terraces should, for the reasons just stated, be more prominent and consist of coarser material, just where the streams emerge from the glacial limit; and such, from a wide collection of facts, is proved to be the rule. I have myself examined nearly all the streams thus emerging from the glaciated area between the Atlantic Ocean and the Mississippi River.* In scores of places where streams thus emerge from the glaciated region—in Pennsylvania, Ohio, and Indiana—their valleys are filled with an accumulation of water-worn northern drift, which, when followed downward, becomes gradually less in amount, as well as more water-worn, and finer in its constituent elements.

This is notably the case in the Delaware Valley, at Belvidere, N. J.; in the Susquehanna, at Beach Haven, Pa.; in the Conewango (as already described), at Ackley, Warren county; in Oil Creek, above Titusville; in French Creek, a little above Franklin; in Beaver Creek, at Chewtown, Lawrence county; on the Middle Fork of Little Beaver, near New Lisbon, Ohio; on the east branch of Sandy Creek, at East Rochester, Columbiana county; on the Nimishillin, at Canton, Stark county; on the Tuscarawas, at Bolivar; on Sugar Creek, at Beech City; on the Killbuck, at Millersburg, Holmes county; on the Mohican, near the northeast corner of Knox county; on the Licking River, at Newark; on Jonathan Creek, Perry county; on the Hocking, at Lancaster; on the Scioto, at Hopetown, just above Chillicothe; on Paint Creek, and its various tributaries between Chillicothe and Bainbridge; and on the Wabash, above New Harmony, Ind.; to which may be added the Ohio River itself, at its junction with the Miami, near Lawrenceburg.

Some of these instances are sufficiently interesting and

* "Glaciated Area of Ohio," in the "American Journal of Science," vol. cxxvi, 1883, pp. 1–14; "American Naturalist," vol. xviii, pp. 755–767.

instructive to warrant a special description. The upper part of the Ohio River, between Pittsburg and New Richmond, in the vicinity of Cincinnati, lies entirely outside of the glaciated area, while nearly all of its northern tributaries rise within that area. In the happy phraseology of Professor Dana, the Ohio River becomes, therefore, the great *distributor*, while its northern tributaries are the principal *contributors*, of terrace material. Now, it is observable that, wherever a large contributor of drift material comes in from the north, there is a great increase in the extent and height of the terraces for some distance below, and the material of which the terrace is composed is coarser at these points. For example, in the neighborhood of Cincinnati, the Ohio is joined by the Little Miami, and twenty miles below, at Lawrenceburg, by the Great Miami. Throughout their entire course these tributary streams flow through a region deeply covered with glacial deposits. As a consequence, the terraces here are of great height and width. At Cincinnati, the upper terrace upon which the original city is built is one hundred and twenty feet high; and at Lawrenceburg the valley, from three to four miles wide, is nearly filled to a height of one hundred and twelve feet above the flood-plain, with a terrace deposit clearly derived from the glacial floods of the Great Miami and its tributaries. Below this point the terraces of the Ohio gradually diminish in height, and the material becomes finer, and more and more water-worn. Above Cincinnati there is a marked development of the terraces at the mouth of the Scioto, at Portsmouth; and again, below Marietta, at the mouth of the Muskingum, where, opposite Blennerhassett Island, the terraces are in the neighborhood of one hundred feet above the present low-water mark. It is to be noted that both of these streams were so situated as to be among the largest contributors to the Ohio, both of glacial floods and glacial *débris*.

But the most instructive place for the observation of this class of phenomena is to be found in Pennsylvania, at the junction of Beaver Creek with the Ohio River. From the

mouth of French Creek, at Franklin, Pa., to the mouth of Beaver Creek, twenty-five miles below Pittsburg, a distance of about one hundred and fifty miles, no contributors of glacial material enter the Alleghany or the Ohio River, and the course of the river-bed lies wholly in the soft, sedimentary deposits of the coal-measures. Consequently, while this portion of the stream contains terraces with northern drift brought into the Alleghany above Franklin, they are of diminishing height, and contain a constantly diminishing amount of material from the glacial drift all the way down to the mouth of the Beaver.

At the mouth of the Beaver there is a sudden enlargement of the Ohio terrace, and it rises at once to a height of one hundred and twenty feet above the river. Upon the lower side of the Beaver, in the angle between it and the Ohio, down-stream, this terrace is very extensive, and the material very coarse, the terrace being, indeed, largely built up of pebbles and bowlders from a few inches to two feet or more in diameter, and all thoroughly rounded. On the opposite side of the Beaver, in the angle between its mouth and the upper portion of the Ohio, there is, for a limited distance, a terrace of equal height, but of entirely different composition from that upon the lower side. The terrace upon the upper side consists of fine material, being mostly sand and gravel derived from the coal-measures, through which the Ohio itself has cut its way. Pebbles from the northern drift are rare, and the local origin of the material is manifest at a glance. What, now, makes this difference between these terraces upon the opposite sides of this small tributary of the Ohio? A glance at the map will show.*

The Beaver River emerges from the glaciated region only a few miles to the north of its junction with the Ohio. The larger part of its drainage-basin lies in portions of northeastern Ohio and northwestern Pennsylvania, which are deeply covered with the terminal deposits of the continental ice-

* See map, p. 145.

sheet. The floods characterizing that period had access to an unlimited amount of material, which was easily swept into the current, and rolled down the torrential bed toward the Ohio River. Upon reaching the Ohio, the combined current of the two streams in the larger valley would have far less power of transportation than the constricted current in the channel of the glacial tributary. The bowlders would, therefore, be deposited at the mouth of the Beaver, where it joins the Ohio, and, owing to the influence of the current of the Ohio itself, would be carried below the junction of the two rivers. Hence it is that we find so many glacial bowlders below the junction, and so few above it. The accumulation of a terrace of an equal height above the junction, but consisting of fine and local material, is also what would be required by theory as well as what is found to be the case in fact. Thus we have, in this single instance, one of the best possible verifications of the glacial hypothesis.

Of the glacial terraces on the Delaware River, from the Water-Gap to Trenton, N. J., there will be occasion to speak more fully when treating of the subject of man's relation to the Ice age in North America. Nor can we more than allude to those which line the Mohawk and the troughs of the Hudson and its tributaries. It is sufficient to say that the passengers upon the New York Central Railroad can satisfy themselves of the existence of these terraces east of Little Falls, N. Y., and between Schenectady and Albany, by merely looking out of the car-windows toward the north; and a moment's reflection upon the topography of the country will show that the terraces of the Mohawk and the upper Hudson are much more recent than those of the Susquehanna and the Delaware, since glacial streams could not have occupied the Mohawk until after the ice-front had retreated from northeastern Pennsylvania and the highlands of southern New York, in which the drainage-basins of the Susquehanna and the Delaware River are situated. When, therefore, the glacial floods of the Mohawk were at their height, the Delaware and the Susquehanna had been relieved of

their excessive burdens, and had subsided to something like their present volume.

As illustrating the capacity of the glacial theory to explain the otherwise unaccountable facts connected with the recent changes in the drainage of the glaciated region, attention is directed to two or three interesting localities east of the Alleghanies, where the dry beds of abandoned streams have been discovered.

We will first consider the outlets of an interesting glacial lake which temporarily occupied the upper part of Contocook Valley in Hillsborough county, N. H., the details concerning which were furnished as early as 1878 by Mr. Upham, in the New Hampshire Geological Report. The Contocook River now empties into the Merrimack a little above Concord, and flows in a direction north-northeast. As a consequence, the present outlet was, toward the close of the Glacial period, obstructed by ice some time after it had melted off from the southeastern portion of the valley. During that period a lake was held in the portion of the valley freed from ice, at a height sufficient to turn the drainage temporarily to the south and southeast. At first the drainage was over the water-shed in Rindge, through Ashburnham and Winchendon, Mass., and thence into the Connecticut. The reality of this line of drainage is evidenced by the extensive kames and gravel deposits extending from the Contocook Valley through the towns of Rindge and Winchendon. When the ice had withdrawn a little farther north, an outlet was open to the southeast into the Souhegan River, and thence into the Merrimack. The evidence here is also conclusive that, for a period, a stream of water eighty feet deep poured through this pass, and the lake formed in front of the ice was in its greatest extent thirty miles long, and from two hundred to two hundred and fifty feet in depth. The evidence of this remains in delta terraces at that level formed at various points where streams came into the lake.

Another instance is in Grafton county, N. H., on the line of the Northern Railroad, between Grafton Centre and East

Canaan, on the water-parting between the Merrimack and the Connecticut, where there is to be found the dry bed of a river which for a time flowed through a pass from the Connecticut Valley into the Merrimack, but which is five hundred feet above the valleys. Here upon this mountain axis, in central New Hampshire, nine hundred feet above the sea, are numerous and large water-worn circular cavities in the rock, technically known as *pot-holes*, such as are formed in shallow rapids, wherever gravel and pebbles become lodged, first, in some natural slight depression, and then, through the whirling motion given them by the running water, these continue to wear a symmetrical depression so long as the supply of water continues, or until a channel has been cut through. Pot-holes may be seen in the rapids of almost any rocky stream, with the gravel and pebbles, which do the immediate work when set in motion, still partially filling them. Such pot-holes exist in the anomalous position mentioned in New Hampshire, where no present stream could by any possibility be made to flow. One of them, measured many years ago by Jackson, was eleven feet deep, four and a half feet in diameter at the top, and two feet at the bottom, and, when discovered, was filled with earth and rounded stones.*

The explanation of this phenomenon furnished by Mr. Upham, while engaged on the New Hampshire Survey, is as follows: The ice of the Connecticut Valley, being farther from the glacial front, lingered considerably longer than that in the Merrimack Valley to the southeast, so that for a considerable period the drainage from the ice-front in the southeastern part of Grafton county was compelled by the ice barrier on the west to flow over this depression into the Merrimack basin, thus furnishing exactly the conditions necessary for the production of pot-holes and such other marks of water-action as have so long puzzled geologists at this point.

Similar pot-holes, to be accounted for in like manner, have recently been described near Archibald, in Blakely

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* "New Hampshire Geological Report," vol. iii, pp. 63–66.

township, Lackawanna county, Pa.* The principal one is from fourteen to seventeen feet in diameter at the top, and is forty feet deep—the sides being very smooth. The depression is worn through strata of sandstone, shale, and coal. The pebbles which did the wearing were still in the bottom of the hole when it was discovered, and are mostly of foreign origin, though some of them consisted of pebbles cut from the coal-bed itself. The elevation is eleven hundred and twenty-nine feet above tide, and no explanation seems possible except that which assumes that a stream of water was kept running in that position for a limited period by ice-barriers.

In passing, it is interesting to remark that the study of the glacial deposits in the coal region becomes of great practical interest from the relation of their buried channels to mining industries. Not only is there money to be saved by knowing the depth of the till, and the inequalities of its distribution, but the lives of the miners are seriously jeopardized by ignorance upon this point. On December 18, 1885, at Nanticoke, near the vicinity of the pot-hole just described, one of the most shocking mining disasters on record occurred, from miscalculating the course of a buried preglacial channel, which was penetrated by the miners in an unexpected place, causing a flood of quicksand, mud, and bowlders to fill the mine and immolate twenty-six miners beyond hope of rescue.

Another instance of glacial drainage worthy of record is reported by Professor J. E. Todd from the Missouri coteau in Dakota. Crow Creek flows westward, and enters the Missouri in Buffalo county, heading well in the terminal moraine:†

Two of its principal branches lead us into the heart of the great interlobular moraines, the Rees, and the range of which Turtle Point is the head, *then by unmistakable channels through* them to the inner side of the moraine and *out upon*

* "Annual Report of the Pennsylvania Geological Survey," 1885, pp. 615-620.

† See map, p. 216.

the great ice-sheet itself. It produces strange sensations to pass up those dry, flat-bottomed valleys, with a steep bank on either hand fifty to one hundred and fifty feet in height, almost built of bowlders; huge cones of gravel, evidently formed in ancient eddies, here and there in the valley; similar valleys joining it now and then. You press on, wondering where the beginning can be, for your map tells you that there are streams which must cut right across its course if it continues as far as you might judge from its width. You press on eagerly, you note the banks rapidly subsiding, but the channel you tread still preserves its gradual rise, then suddenly you come out upon the face of the range, and a magnificent view of the plain, two hundred to three hundred feet below, bursts upon you. You look for the inclined plane which by easy steps has brought you to this altitude, and find it ending abruptly with the face of the hills. You realize, as never before, the mass of ice which once must have occupied the expanse before you. You can see that stream, scores of yards in width, leaving its icy banks, now vanished in thin air, for the stony ones which still remain.*

It seems clear, also, that the disturbing effects of the great ice-sheet upon the drainage of the Northwest will account for the numerous deserted river-valleys described by Dr. G. M. Dawson in the part of British America lying between the Lake of the Woods and the Rocky Mountains. Here the conditions were somewhat peculiar. The natural drainage is down the flanks of the Rocky Mountains eastward to the Red River Valley. The Saskatchewan River drains the northern portion of the territory, while the Assiniboin with its branches, the Qu'Appelle and Souris, drains the southern portion—the drainage-basin of the Souris joining that of the Missouri in Dakota. The Pembina River, a much smaller stream, empties into the Red River near the boundary-line, considerably south of the Assiniboin; and the Sheyenne still farther south.

* "Proceedings of the American Association for the Advancement of Science," vol. xxxiii, 1884, p. 391.

With the interpretation which the present discussion has put upon the facts, the following is the order of events: During the farthest extension of the ice to the vicinity of the Rocky Mountains, the South Saskatchewan was compelled to flow around the front of the ice-sheet to join the Milk River at the boundary-line near the one hundred and tenth meridian, and thence into the Missouri. A great dry *coulée*, a portion of which is occupied by a large saline lake known as Peekopee, is a marked feature connecting these streams at the present day.*

Coming eastward to the one hundred and second meridian, the Rivière des Lacs seems, without doubt, to have been the line of drainage for the Souris River for a distance of seventy-five or eighty miles. Characteristically enough, this ends northward, near the Souris River, "in a broad dry *coulée*, which shallows and dies away in a strip of bowlder-covered ground, which stretches northward toward the Souris River, five miles distant, and is somewhat lower than the general surface of the plain."

At this time there was a lake-like expansion of water in the Elbow of the Souris, covering Renville, Ward, and McHenry counties, Dakota, the evidence of which is still plainly seen. This lake, again, was forced to seek a southern outlet, which it found through a *coulée* in McHenry county into the head of the Sheyenne River, and thence followed its winding course to Lake Agassiz, near Fargo, where there is an immense delta of river gravel.

Coming still farther east, the Pembina River occupies a valley very much larger than its present demands; and, at its junction with the Red River, there is also an immense gravel delta, indicating it as a line of drainage at one time of a far larger area than now. Upon following the valley of the Pembina up, it is found to continue through the Pelican Lake to the Elbow of the Souris, near the one hundredth

* "Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel," pp. 262–268.

meridian, and twenty-five or thirty miles south of the Assiniboin. Professor Hind finds evidence that this was the outlet temporarily not only of the Assiniboin but, through the Qu'Appelle and the River that Turns, to the South Saskatchewan. Mr. Upham writes me that he has followed this old valley for one hundred and twenty-five miles as far as Birtle, in Manitoba. According to Professor Hind, the length of the valley of the Qu'Appelle, from Birtle up to the Saskatchewan, is two hundred and sixty-eight miles in direction northwest by southeast. The valley is uniformly about one mile wide, and from one hundred and ten to three hundred and fifty feet below the general level, and eighty-five feet above the present level of the South Saskatchewan, the descent being four hundred and forty feet from the Saskatchewan to the Assiniboin. The inclosing bluffs consist mainly of till, and the whole trough is characterized by numerous long, shallow lakes. These lines of marginal drainage are readily explained upon the glacial hypothesis here maintained, and are a strong proof of that hypothesis. As the ice receded, more northern outlets were opened, and these temporary channels were naturally abandoned.

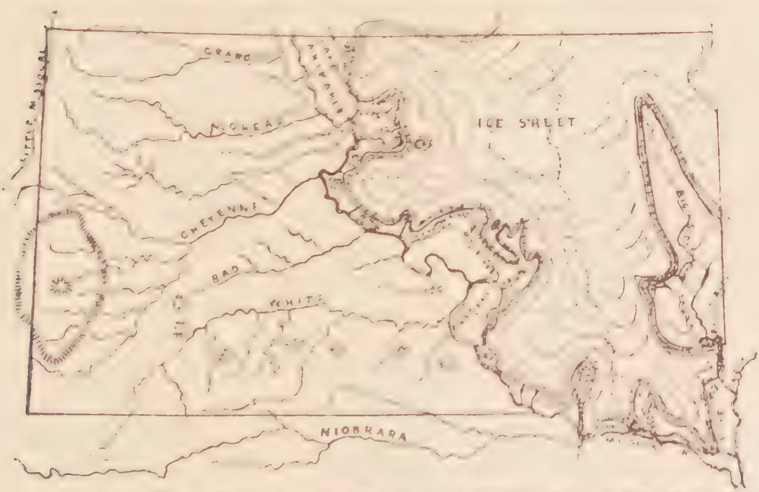

FIG. 100—Map of South Dakota showing the extent to which the channel of the Missouri River was permanently changed during the early Wisconsin epoch. The broken lines indicate the former course of the Grand, Cheyenne, and White Rivers as they joined the original Missouri when flowing through the James River valley. (Map by Todd.)

According to Professor Todd the preglacial Missouri River entered the valley of the James near its upper portion, reaching its present channel at Yankton. Having filled this valley, the advancing ice from the northeast obstructed the mouths of the Grand, Moreau, Cheyenne, and White river and, forcing the drainage in front of the ice across the cols between these streams, gave rise to the present tortuous channel across the State of South Dakota. Lake Arikaree was one of the temporary results of this advance. Its shore lines being clearly traced at a height of 400 feet above the the present Missouri. The bowlders near the Moreau River and the deserted river bed mentioned on pages 146 and 147 are connected with the existence of this lake.

Coming still farther southeast, we find that the Minnesota River makes a sharp turn to the north at Mankato, and so is favorably situated for having its drainage reversed while the ice rested over the counties about its junction with the Mississippi near St. Paul. The facts are found to be according to the programme. There is abundant evidence of a temporary lake, covering the territory of Blue Earth and Faribault counties, which emptied through a channel known as Union Slough, about eight miles long and from one-eighth to one-fourth of a mile wide, with bluffs from twenty to thirty feet in height, which connect Blue Earth River with the Eastern Branch of the Des Moines in Kossuth County, Iowa.

In this connection it is in place also to refer to the dramatic history of Lake Bonneville during the Glacial Period, though a fuller account will be necessary in future chapters (see pages 615 and 703). This body of water accumulating in the basin of Great Salt Lake during the moist and cool climate of that period attained a depth of 1,000 feet, covering an area of 20,000 square miles. At this elevation there is a distinct shore line traceable around the whole distance, broken into occasionally by terminal moraines of the glaciers that came down from the Wasatch mountains. Near the northeast corner of the basin a dirt dam had been formed 375 feet high

by the wash from the mountains on either side. This dam separated the basin from the Port Neuf river which debouches upon the Snake river plain at Pocatello. Evidently when the opening was once made the whole body of water from the upper 375 feet of Lake Bonneville poured down this little valley in torrents which baffle all our descriptive powers. Evidence of its torrential action are visible all along the valley and especially at Pocatello where an immense bowlder bed was deposited. (See figures on pages 615 and 703.)

Note to the Fourth Edition.—Since the following chapter upon "Kames" was written, a partially successful effort has been made to distinguish between kames and eskers; but the distinction is not so well defined as to make it necessary to rewrite the chapter. According to Professor Chamberlin (see Geikie's "Great Ice Age," third edition, p. 746), eskers denote the long gravel ridges which conform in general to the direction of the ice movement, while "kames take on the form of bunchy aggregations of knolls and irregular ridges, and have a tendency to arrange themselves in belts parallel to the margin of the ice." But "it is not to be understood that any sharp line of distinction can be drawn between the two types. They are connected by intermediate forms which are difficult to place in either class. The kames, as well as the eskers, are regarded as products of glacial drainage."

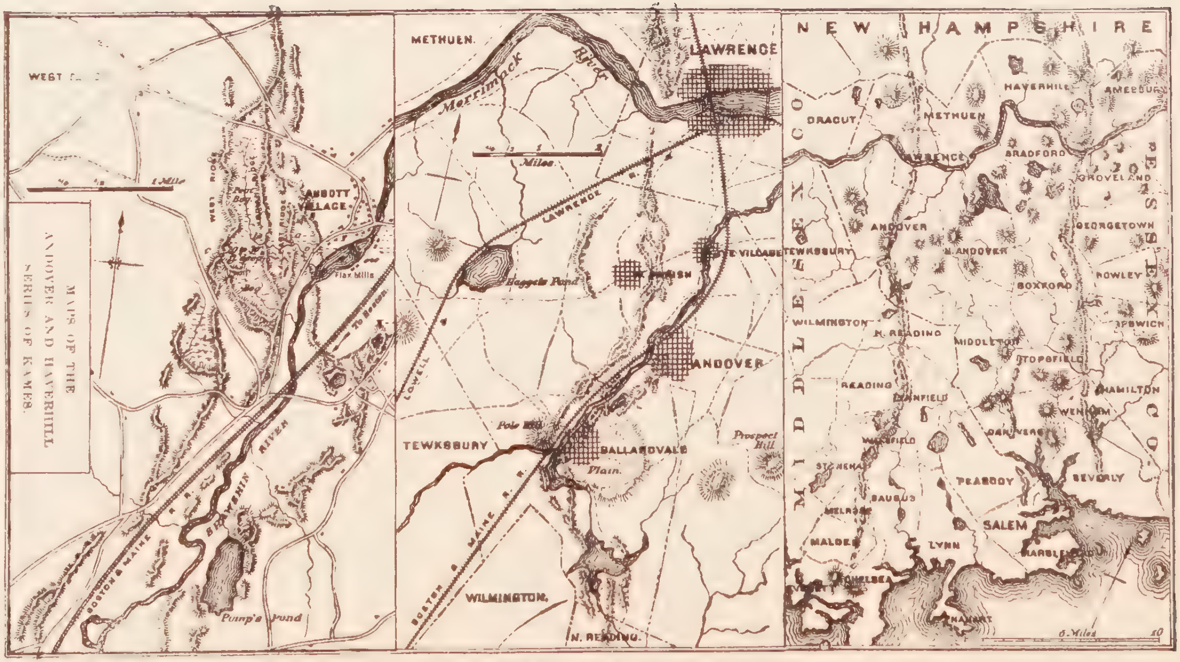

FIG. 101. Series of maps showing, on the left hand, details of the kames in Andover, Massachusetts; in the middle, the extension of these kames through the town, showing the manner in which they cross the Shawshin and Merrimack Rivers; on the right hand the extension of the series both north and south of Andover, with a parallel series crossing the Merrimack near Haverhill. The hills marked are drumlins, some of which are partly covered by the kames.

CHAPTER XIV.

KAMES.

The word "kame" has already been defined as a local term applied to the sharp gravel ridges which abound in various parts of Scotland, and which in Ireland are called "eskers," and in Sweden "osars." As Mr. Geikie's work on "The Great Ice Age" has given currency to the Scotch name, and as the word has been adopted by those who have investigated this class of formations most fully in America, it seems best to continue its use, though either of the other names is more euphonious. This class of ridges was first described in this country in 1842 by President Edward Hitchcock. Speaking of the gravel deposits in Andover, Mass., known as Indian Ridge, he says they are "a collection of tortuous ridges and rounded and even conical hills with corresponding depressions between. These depressions are not valleys which might have been produced by running water, but mere holes, not unfrequently occupied by a pond." * The fuller description of their composition by Mr. James Geikie is as good for America as for Europe:

The sands and gravels have a tendency to shape themselves into mounds and winding ridges, which give a hummocky and rapidly undulating outline to the ground. Indeed, so characteristic is this appearance, that by it alone we are often able to mark out the boundaries of the deposits with as much precision as we could were all the vegetation and soil stripped away and

* "Transactions of the American Association of Geologists and Naturalists," 1842.

the various subsoils laid bare. Occasionally, ridges may be tracked continuously for several miles, running like great artificial ramparts across the country. These vary in breadth and height, some of the more conspicuous ones being upward of four or five hundred feet broad at the base, and sloping upward at an angle of twenty-five or even thirty-five degrees, to a height of sixty feet and more above the general surface of the ground. It is most common, however, to find mounds and ridges confusedly intermingled, crossing and recrossing each other at all angles, so as to inclose deep hollows and pits between. Seen from some dominant point, such an assemblage of kames, as they are called, looks like a tumbled sea—the ground now swelling into long undulations, now rising suddenly into beautiful peaks and cones, and anon curving up in sharp ridges that often wheel suddenly round so as to inclose a lakelet of bright clear water.*

From this description it will be seen that there are some remarkable resemblances between kames and terminal moraines, since both of them are characterized by confused hummocks and tortuous ridges of glacial *débris*, connected with numerous bowl-shaped depressions, often containing

FIG. 102.—Section of kame near Dover, New Hampshire. Length, three hundred feet; height forty feet; base, about forty feet above the Cochecho River, or seventy-five feet above the sea. *a, a*, gray clay; *b*, fine sand; *c, c*, coarse gravel containing pebbles from six inches to one foot and a half in diameter; *d, d*, fine gravel. (Upham.)

lakelets. But in other respects there is a marked difference between them. In the first place, the material of which kames are formed is ordinarily much finer and more water-worn, and shows more abundant signs of stratification than that of which terminal moraines are composed. Secondly, while the terminal moraine forms a ridge at right angles to the motion of the glacier, and marks the limit of its exten-

* "The Great Ice Age," pp. 210, 211.

PLATE IX.—Typical kames near Hingham, Massachusetts. The parallel ridges of gravel in the foreground run nearly east and west, and coalesce at each end, near the edges of the picture, to form an elongated kettle-hole. The ridges from fifty to sixty feet in height. The kame stream was here evidently emptying into the ocean a few miles to the east. (Bouvé.

sion during a prolonged period, the kames approximately coincide in direction with the lines of glacial striæ. A large part of New England is covered with kame deposits, arranged, in general, along the main lines of present drainage, with merely such anomalous exceptions as can readily be explained by the interference which the ice itself offered to the course of the floods which characterized the last stages of the Glacial period.

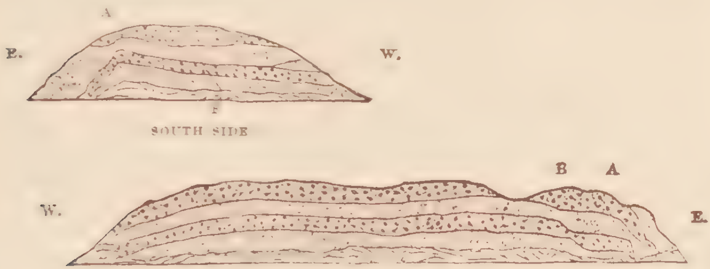

FIG. 103.—Sections of a kame at Bennington Station, New Hampshire. Scale about forty feet to the inch. The upper figure shows a simple transverse section; the lower figure is directly transverse on the right side, but longitudinal on the left. Counting from the top the strata are: 1, coarse yellow gravel, with pebbles up to eight inches in diameter, thickness, three to five feet; 2, fine sand, three to five feet; 3, coarse, dark gravel, containing pebbles up to one foot in diameter, three feet; 4, fine sand, obscured at the bottom by crumbling of the bank, four to eight feet; A. A. downfall of strata with irregular, broken, steep slope, against which lies an accumulation of sand; B. depression of two feet, similar to the foregoing; F. fault, seen only on the south side, dislocation of strata, six inches. (Upham.)

The most satisfactory conclusion with regard to the origin of kames is that they mark, in the glaciated region, lines of drainage during the closing stages of the Ice age. It is evident, from a moment's reflection, that the streams of water resulting from the annual precipitation, combined with that from the wasting of the ice during these closing stages, must have been enormous, and may very likely have flowed in channels quite different from those chosen after the ice had completely melted away. Of course, these glacial streams must, in the main, have followed the great valleys; but many of the minor valleys were, at that time, so obstructed that the streams might disregard them and take a more direct route over the ice through the open channels and long tunnels which must then have existed. Those familiar only

with the contracted glaciers of the Alps are scarcely prepared to appreciate the extent to which currents of water flow over the larger glacial masses and rearrange and transport the superficial material collected upon them. The "subglacial" streams also are not always strictly subglacial, since they often flow through tunnels which are midway between the top and the bottom of the ice-mass. In the Muir Glacier, Alaska, for example, the two streams issuing from the ice-front near the sides of the glacier are several hundred feet above the level at which the two streams emerge near the center of the channel. There, also, streams of water of more or less size can occasionally be seen pouring out from the perpendicular front of the ice a hundred or more feet above the surface of the inlet. Nor is it any uncommon thing to see icebergs move off with water-worn tunnels in them which are still well filled with gravel and pebbles. In the various depressions in the surface of the glacier also, where at times extensive lakes of water are formed, there is much accumulation and assortment of earthy material far back from the terminal margin of the glacier.

We will now endeavor briefly to reproduce the conditions in New England near the close of the Ice age, in order to see how the facts fit into the theory just enunciated.

The main north-and-south valleys of New England are now drained by the St. John, the St. Croix, the Penobscot, the Kennebec, the Androscoggin, the Merrimack, and the Connecticut Rivers, with various smaller subordinate drainage-basins, such as the Machias, the Saco, and the Piscataqua. The larger valleys are also joined by various subordinate ones, tributary to them, running in various directions conformable to the general contour of the country. But the present course of the rivers is not necessarily determined at every point by barriers of any great height. For example, there are no high barriers separating the northeastern portion of the Penobscot drainage-basin from the sources of the St. Croix and Machias Rivers. South of the Rangeley Lakes, also, where Ellis River joins the Androscoggin, it is

only a barrier of two or three hundred feet which causes the present deflection of the river to the east, through Lewiston to Brunswick. The great bend made by the Merrimack River at Lowell, Mass., is also caused by a glacial deposit to the south of only fifty or sixty feet in height.

It is easy to see that, during the period of most rapid retreat, when the waters of the wasting ice-sheet over New England were seeking their ultimate channels, the lower portion of the ice itself was an important element in determining the minor deflections in these lines of drainage. An ice-barrier of a few hundred feet in the Penobscot, between Passadumkeag and Mattawamkeag, would force the drainage of the Aroostook region into the valley of the Machias, and, in the predominance of the mountains from which the western branches of the Penobscot River descend, we have a cause favoring such an extension of the ice as would produce the results indicated. In the case of the Merrimack River, the fact that, from Lowell to Newburyport, it flows in a northerly direction would also furnish a probable ice-barrier which for a time would drive the drainage of this basin directly southward from Lowell and Lawrence toward Boston.

It is not necessary to go into all the details concerning the intricate network of kames which mark the lines of drainage over New England, when ice-barriers to so great an extent directed the flow of the glacial torrents. The facts are impressive. Individual kames can be traced for long distances, sometimes a hundred miles or more. The main lines in New England are shown on the accompanying map, beginning on the eastern side of Maine.*

A few points merit particular attention. The Connecticut River Valley, from its sources to the Massachusetts line, contains the remnants of what seems to be a pretty continuous kame, but which has been largely eroded, and in many cases covered up by subsequent deposits of river-silt. Almost

* See also "Kames and Moraines of New England" in "Proceedings of the Boston Society of Natural History," vol. xx, p. 211 *et seq.*

everywhere we find illustrations in the partial burying of kames by such river-silt that the deposition was previous

FIG. 104.—The kames of Maine and southeastern New Hampshire. The extension from New Hampshire can be seen in FIG. 101. (Stone.)

to and independent of the present streams. For example, the Merrimack, between Lowell and its mouth, is crossed at right angles by two or three lines of kames, which descend into the valley from one side and come out upon the hills on the other. While crossing the valley these are partially,

and in some places completely, buried beneath the river-silt which forms the present flood-plain. In one case, a few miles below Lowell, the end of this ridge, completely covered with river-silt, may be seen where the river has cut across the old barrier. Professor Charles Hitchcock gives a similar section of a buried kame in Hanover, N. H., though

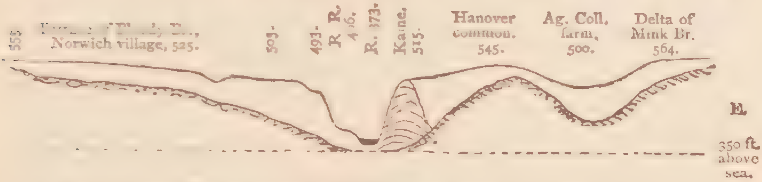

FIG. 105.—Section across the Connecticut Valley, from Norwich, Vermont, to Hanover, New Hampshire, distance three miles. The kame is nearly covered by later river silt. (Upham.)

in this case it is parallel with the river, and not, as in the other, at right angles to it.*

Inasmuch as the interpretation of the facts in the valley of the Connecticut is open to some question, and as the decision with respect to them will have an important bearing on our whole conception of the closing scenes of the Glacial period, it will be worth while to consider them more fully.

Mr. Upham, in his survey of the Connecticut Valley,† discovered what he considered to be a line of kames extending throughout nearly the whole length of the valley, though it had been much eroded in places, and in others was partially or completely buried by river-silt; but of the character of the deposit as a true kame he felt quite confident—that is, he considered that the line of gravel ridges which he found winding from side to side down this valley were deposited as the ice retreated, after the manner we have described in channels and tunnels formed near the front. In this view these ridges in age are intermediate between the till and the regular river

* "Proceedings of the American Association for the Advancement of Science," vol. xxxi, p. 328; also Upham, in "Geology of New Hampshire," vol. iii.

† See "Geology of New Hampshire," vol. iii, pp. 3–177; also, "American Journal of Science," vol. cxiv, 1877, p. 459.

terraces—being newer than the till and older than the terraces.

On going over the ground in 1881 with Mr. Upham's notes in his hands, Professor Dana concluded that what Mr. Upham had called kames were in reality a portion of the regular terrace formation. In Professor Dana's view, the reputed kames are merely the coarser part of the terrace material accumulated in excessive amount in the larger valley wherever tributary streams brought into it their heavier burdens from the higher land. On this theory, the height of the floods in numerous localities must have been between two hundred and three hundred feet above low water in the river; for in various places these deposits are at that height above the river. But upon the supposition that they are

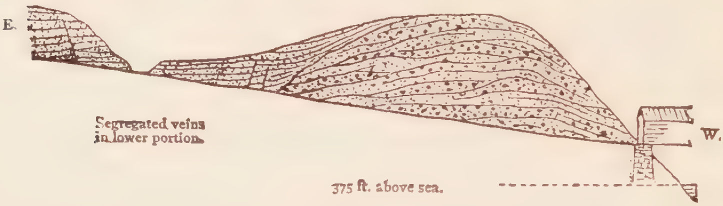

FIG. 106.—Section east from Ledyard Bridge, Hanover, New Hampshire, showing segregated veins in the lower portion. Length, about seven hundred feet. Height of kame above the river, one hundred and forty feet. (Upham.)

kames, deposited when the ice itself formed barriers to keep the streams in various abnormal positions, the glacial floods would not need to be more than from one hundred to one hundred and fifty feet in height, since that is all that is required for the deposition of the highest river-silt which occurs.

It must be confessed that Professor Dana's estimates of the size of the Connecticut River floods at that time are somewhat startling, even with all the changes of level for which he provides in his theory.* For, after reducing, by reason of the Champlain depression, the gradient of the stream during the close of the Ice period by one third, the

* "American Journal of Science," vol. cxxiii, 1882, p. 198.

slope of the surface of the Connecticut would still have been more than one foot per mile. This, in a torrent 2,500 feet wide, with a depth of 140 feet, would produce a current of eight miles per hour on the surface and of six miles on the bottom. With this size of the flood, the rate of discharge would be about four hundred cubic miles of water per annum; whereas, at the present time, the total discharge of a year is only about five cubic miles. To cause this enormous rate, Professor Dana supposes that, for a short period, the Connecticut glacier melted at the rate of more than a cubic mile per day. As he estimates the area of this drainage-basin to be about 8,500 square miles, this would imply that at times as much as eight inches per day melted from this surface. This rapid rate of removal in summer is not, however, supposed to continue for a long period—probably less than five years. Professor Dana supposes that, at that time, the long tunnels worn in the glacier by the Connecticut and its tributaries, when they existed as subglacial streams, had become open channels in the ice.

Later and fuller investigations of Professor Emerson, give a different interpretation to many of the facts in the Connecticut Valley. It would now appear that the ice disappeared from the high lands on either side before it did in the valley, so that there was a series of marginal lakes at successively lower levels leaving accumulations of gravel, and these were traversed occasionally by kame-like ridges. This conforms to what was evidently the course of events in the Champlain Valley parallel to it. There high-level gravel deposits which were at first supposed to be indications of a general depression of land, are explainable on the theory of marginal glacial lakes.

The shore lines of such marginal lakes are clearly marked at Bakersfield, Franklin County, Vermont, and southward in the valleys of the Lamoile and Winooski rivers. The bowlder channel in Chazy, N. Y., described above, p. 320, marks as already said a water weir between the decaying ice-sheet and the Adirondack Mountains.

The levelly stratified plains of sand and gravel which spread out around the southern end of the kame systems, and which to a greater or less extent border their margin throughout their entire length, should not be passed without notice,

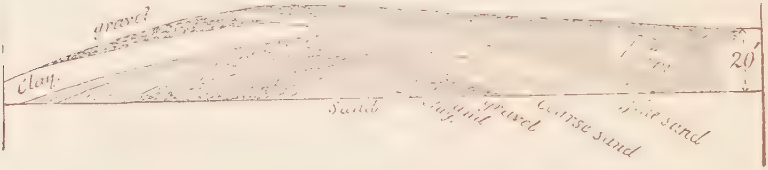

FIG. 107.—Buried kame near Stroudsburg, Pennsylvania. (Lewis and Wright.)

since they in a remarkable degree confirm our general theory concerning the origin of kames. As has been said, the kames mark the great lines of drainage which poured over the southern margin of the glaciated area during its later stages when the ice itself furnished numerous and important barriers to direct the torrents, and when the earthy material in and on the ice was readily at hand to be swept along by these temporary streams. The pebbles, sand, and gravel lodged by the way in the ice-channels, and on the surface, furnished the material from which the kames were to be formed. Wherever these streams came out of their confinement and flowed over a level country, they deposited vast deltas of sand and gravel, analogous to those that are now being deposited at the mouths of all large rivers. One of the most remarkable of these kame deltas is that in Cherryfield and Deblois, near the eastern coast of Maine. This sandy plain, many miles in extent, is not an ocean deposit, but can be readily connected with the streams which deposited to the north of it one of the largest belt of kames in the State, and whose course can be traced for nearly one hundred miles toward Mount Katahdin. Down the line of the kame there poured, between icy walls, during the closing stages of the Glacial period, a vast but fitful silt-laden stream of water, which, as it emerged from its more constrained limits within the ice-sheet, was slackened in its movement and rapidly de-

posited the strata of sand and gravel forming the above-mentioned delta-plain.*

This is but a type of innumerable other places. As the ice receded and the mouth of the kame-streams retreated to the north, the line of these deposits receded, and deltas were pushed out now upon one side and now upon another of the central kame. Often one can see these aprons of stratified deposits stretching out from the base of the kame into a swamp, the stream at that point not having been stationary long enough to allow the whole depression into which it was flowing to become filled with silt. Nearly all of the extensive gravel deposits in New England are thus related to some kame system, so that, when once their origin became understood, they were the means of assisting in the discovery of the kames themselves. An interesting illustration of this occurred in the case of the kames running through the Rangeley Lakes from north to south, and extending to the Androscoggin River and beyond, south of Andover, Me. From the extent of the gravel plains to the north of Portland, Mr. Upham had surmised that a kame-stream must have come down from the north to account for the deposit. My brother, Rev. W. E. C. Wright, was soon after requested to look for such a kame in the course of a pleasure-trip he was about to make to these lakes. This he did, and the result was that, what Mr. Upham had seen with the mind's eye, the summer tourist had no difficulty in finding in reality. The kame can be traced up the stream not only to the lakes, but through and across them—their backs appearing occasionally above the water, and their line forming a shoal from one side to the other

These aprons of over-wash gravel, marking the deltas of the kame streams during the close of the Ice age, also characterize the whole glacial border to a greater or less extent. The entire south side of Cape Cod and of Long Island † pre-

* See map, p. 344.

† See "The Geological Formation of Long Island, New York, with a Description of its Old Water-Courses," by John Bryson, 1885.

sents a bordering plain of sand and gravel, deposited, in the manner above described, about the base of the great terminal moraine, and decreasing in height as the distance increases from the base to the south. Similar deposits characterize the southern flanks of the kettle-moraine of Wisconsin and its extensions both east and west. Several such are crossed upon the railroad from Elkhorn to Eagle, in Walworth county, Wis., where the hills of the moraines are to the north, and much low, swampy land lies to the south and east. It is evident that the ice remained here just long enough for the currents of water which swept down from the moraine to fill the depression with sand and gravel from its base down to the line of the railroad, whereupon the retreat of the ice-front allowed the course of the drainage to change, and to build up deltas at some other point.

The discussion of kames is not complete without directing attention to the fact that they do not by any means always occupy a continuous slope from the highlands to the glacial margin; and this has an important bearing upon the question of the mode of their formation, and their connection with ice-barriers and with ice-channels. Frequently, when following a kame down a gentle incline or over a level plain, it will be found that, on coming to a transverse valley one hundred and fifty or two hundred feet in depth, and perhaps more, the kame is not interrupted, but it descends into the valley on one side, and ascends on the other to the level plain beyond. This feature of the kames across the Merrimack River above Lawrence, Mass., has already been referred to, and it early attracted my attention, and was fully described in one of my first papers on the subject.*

Another interesting illustration of this phenomenon, and one which reveals the ingenuity of the investigator, is related by Professor Stone respecting the kame which crosses Schoodic Lake in eastern Maine. He had followed the kame

* See "Some Remarkable Gravel Ridges"; also, "The Kames and Moraines of New England"; also, map p. 338.

to the north end of the lake, and had also learned of its existence on the south end. Wishing to ascertain whether the kame was continuous to the other end, he inquired of the lumbermen who are in the habit of "warping" rafts of logs through the lake whether there was not a line of shoal water through it. But none of them had become aware of any such shallow line.* On asking them, however, if the anchorage was equally good at all places in the lake, they at once replied that it was not; that at certain places the bottom was gravelly, and the anchors would not hold. Upon asking what they did in such an event, they replied that all they had to do was to take the anchor to one side or the other, when usually there was no difficulty in finding a good bottom. The explanation, to Professor Stone's mind, of this state of things was, that the gravelly places of poor anchorage were along the line of the kame, and, by asking the lumbermen to mark upon the map the places where the anchor was in the habit of dragging, and which they were compelled to avoid, he was able to trace the kame from one end of the lake to the other.

Instances like this, of the indifference of the kames to the minor irregularities of the slopes of the valleys in which they are situated, are frequent. One worthy of special note is found in the valley extending from Wakefield, Carroll county, N. H., northward to Ossipee Lake. In this case two kame systems meet each other in the depression of the lake, having slowly descended for many miles, the one from the north and the other from the south. The explanation is that the outlet of Ossipee Lake is to the east, joining the Saco River at Cornish. Evidently this drainage-channel through the ice was opened while the ice still filled the southern part of Carroll county as far south as the head-

* The process of warping rafts is as follows: An anchor is taken out some distance ahead of the raft and dropped upon the bottom; whereupon a windlass upon the raft connected with a rope that is fastened to the anchor is turned, and the raft is thus slowly drawn to the point over which the anchor is caught, when the anchor is raised and again taken forward, to have the process repeated

waters of the Piscataqua River. Thus there was, along a certain margin of the ice, a backward drainage of twenty miles or more, which offers a ready explanation for this seeming anomaly in the relation of the kame to the general slope of the valley down which the ice had moved.

Several other instances, equally marked, described by Professor Lewis,* exist in the eastern counties of Pennsylvania. In these cases a great amount of glacial *débris* had been deposited upon the ice, a little back from its front, on the west side of the Delaware River, both above and below the Water-Gap. South of the Water-Gap these deposits are several hundred feet higher than the Delaware River, and lie between it and Kittatinny Mountain. When the Delaware had opened its own channel back to the present site of Portland, just below the Water-Gap, a line of backward drainage was established from the higher land on the southwest toward the northeast. This line is now marked for a number of miles by a very well-developed system of kames.

A similar line of kames descends the valley of Jacobus Creek along the line of drainage to the Delaware River, sloping backward from the glacial margin near Johnsonville toward Stroudsburg. Down this backward slope, for a distance of five miles or more, the kames are very conspicuous.

The gravel-ridges occurring in the southern or upper end of the numerous transverse valleys containing the Finger Lakes of central New York seem to be similar instances of kames formed by backward drainage. The course of events there seems to have been as follows: After the ice melted back to the water-shed between the Mohawk and the Susquehanna River, a large amount of water-worn material accumulated upon and about the margin before the great line of drainage through the Hudson and Mohawk Rivers opened. When, finally, the streams of this region were re-

* "Marginal Kames," in "Proceedings of the Society of Natural Sciences," Philadelphia, June 2, 1885, pp. 157–173.

stored to their natural course, and the drainage-line of the Mohawk was resumed, these kames of the Finger Lake region would be naturally formed.

Westward from New York the conditions are not favorable for the formation of this class of glacial deposits. Still, there are numerous short series of kames in Ohio at the low place in the water-shed between the lake and the tributaries to the Ohio River. Through these the glacial torrents poured over into the southern streams during all that period when the outlet through the Wabash was closed up and the dam across the Mohawk Valley was at its height. Kames are abundant in Summit county, between Ravenna and Akron, and southward, and in the neighborhood of Seville, in Medina county.

Occasional kame-like ridges are reported farther west, as in Pipestone county, Minn.* But, according to the testimony of Mr. Upham, whose experience is wider than that of any one else in these investigations, "prolonged kames, comparable with those of Sweden and Scotland, and with those described in Maine, New Hampshire, and Massachusetts, have not been found." †

A summary of the last three chapters may be helpful here:

The extreme length of preglacial as compared with postglacial time is evident from the enormous extent of preglacial erosion. Outside the glaciated region all the rivers occupy deeply eroded valleys, showing the great length of the time through which eroding agencies have been at work. The post-glacial gorge of Niagara is but seven miles long, whereas the preglacial gorge of Ohio is both wider and deeper than that, and is more than a thousand miles in length.

It is easy to see that all the northerly-flowing streams of preglacial drainage would be dammed up by ice during the

* "Geological and Natural History Survey of Minnesota," vol. i of the final report, p. 545.

† Ibid., "Ninth Annual Report," p. 290.

greater part of the Glacial period. Of this as a reality there is abundant evidence. All the streams which rise within the glaciated region and flow southward were compelled to carry away not only the annual precipitation, but, during the closing stages of the period, the waters of the accumulated precipitation of many thousands of years. If the annual spring freshets of these streams are oftentimes terrific, what must have been the spring freshets in the Glacial period itself!

Into the Mississippi also were poured the surplus waters which now flow down the St. Lawrence, and into Hudson Bay. Lake Erie emptied its waters through the Wabash River, and Lake Michigan down the Illinois; while the great region drained by the Red and other rivers of Manitoba and British Columbia had their outlet through Lake Traverse and Big Stone Lake, into the Minnesota, and thence into the lower Mississippi. The terraces of the glaciated region are the direct results of these glacial floods, and can be studied on every stream within its boundary.

Besides the glacial terraces of our present streams, we have, in the so-called "kame systems," still further evidence of the existence of temporary lines of drainage determined by ice-barriers. New England is gridironed by a system of gravel-ridges deposited by glacial streams which were, to a great extent, independent of the minor features in the present topography. In these and in the terminal moraines we study the skeleton of the continental ice-sheet as intelligently as the anatomist can study the skeleton of a dissected animal.

CHAPTER XV.

GLACIAL DAMS, LAKES, AND WATERFALLS.

No single cause has done more to diversify the surface of the country, to add to the attractiveness of the scenery, and to furnish the key by which the conditions of the Ice age can be reproduced to the mind's eye, than glacial dams. To them we owe the present existence of nearly all the waterfalls in North America, as well as nearly all the lakes, while the shore-lines and other marks of temporary bodies of water produced by ice-barriers are of the most instructive character.

In the chapter upon "Glacial Erosion and Transportation" we have already spoken at some length of rock-basins which have been formed by glacial action. In the case of the so-called *cirques* there described, there can be no question that they have been produced by ice-action, the rocks being worn deepest where the ice impinged upon them most directly and for the longest period of time, leaving at the front a rocky rim much higher than the bottom of the *cirque.* To what extent the fiords, and the lakes which are some distance from mountain declivities and have rock-rimmed basins, owe their origin to the same cause, is an unsettled question; and still greater doubt appertains to such basins as are occupied by the great lakes of the United States and British America. Professor Newberry, whose opportunities for investigation have been most ample, would attribute these lake-basins largely to glacial erosion.*

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* "Notes on the Surface Geology of the Basin of the Great Lakes," "Boston Society of Natural History 1862"; "Geological Survey of Ohio, Report of

It is fair to Professor Newberry, however, to state that he never took extreme grounds upon this point, but that his fullest statement of the theory, written for the second volume of his "Report of the Geological Survey of Ohio," was well matured, and gave weight to all the agencies which combined with ice-action to produce these basins. The facts which have to be borne in mind with reference to the Great Lakes are briefly these: 1. Lakes Ontario, Erie, Huron, and Michigan, being surrounded by sedimentary rocks whose strata at the present time lie nearly horizontal, evidently occupy valleys of erosion. The western end of Lake Superior, however, occupies a synclinal trough, and is doubtless partly due to an early warping of the earth's crust. 2. The bottoms of all these lakes, except Erie, are lower than the present sea-level, the depression in the case of Superior being 375 feet; Michigan, 286; Huron, 127; Ontario, 507. If, then, these lakes occupy valleys of erosion, it is an interesting question to determine how any erosive agency could have operated to such a depth below sea-level.

Professor Newberry's theory is that, previous to the Glacial period, the region to the south and southwest of Hudson Bay was considerably elevated above its present position, and that from early ages the lines of drainage had been established in pretty much the same general course as at present, forming valleys of considerable extent where now the lake-basins exist; that, when the Ice age came on, the country to the north was still at a higher elevation than now, and as the local glaciers increased, they occupied, enlarged, and in some cases deepened, these old river-valleys, both by direct action in eroding the rocky basin and by the deposition of great quantities of glacial detritus. But his own statement of the theory is so perspicuous and

Progress for 1869"; "The Surface Geology of the Basin of the Great Lakes and the Valley of the Mississippi," "Lyceum of Natural History Society, New York, 1869"; "The Surface Geology of Ohio," "Report of Geological Survey of Ohio," vol. ii, 1874; "The Geological History of New York Island and Harbor," "Popular Science Monthly," 1878.

condensed that we can do no better than reproduce the most of it:

Previous to the Glacial period the elevation of this portion of the continent was considerably greater than now, and it was drained by a river system which flowed at a much lower level than at present. At that time our chain of lakes—Ontario, Erie, and Huron—apparently formed portions of the valley of a river which subsequently became the St. Lawrence, but which then flowed between the Adirondacks and Appalachians, in the line of the deeply buried channel of the Mohawk, passing through the trough of the Hudson and emptying into the ocean, eighty miles southeast of New York. Lake Michigan was apparently then a part of a river-course which drained Lake Superior and emptied into the Mississippi, the Straits of Mackinaw being not yet opened.

With the approach of the cold period, local glaciers formed on the Laurentian Mountains, and, as they increased in size, gradually crept down on to and began to excavate the plateau which bordered them on the west and south. The excavation of our lake-basins was begun, and perhaps in large part effected, in this epoch.

As the cold increased and reached its maximum degree, a great ice-sheet was formed by the enormously increased and partially coalescing local glaciers of the former epoch. This many-lobed ice-sheet, or compound glacier, moved radiatingly from the south, southwest, and western slopes of the Canadian highlands, its Ohio lobe reaching as far south as Cincinnati. The effect of this glacier upon Lake Erie and Lake Ontario would be to broaden their basins by impinging against and grinding away with inconceivable power their southern margins. To the action of this agent we must ascribe the peculiar outline of the profile sections drawn from the Laurentian Hills across the basin of Lake Ontario to the Alleghanies, and across that of Lake Erie to the highlands of Ohio, viz., a long, gradual slope from the north to the bottom of the depression, and then an abrupt ascent over the massive and immovable obstacle against which the ice was banked, until, by the *vis a tergo*, it overtopped the barrier. In New York that barrier

was a shoulder of the Alleghanies, too high and too rugged to be buried under a continuous ice-sheet; but its whole front was worn away for a hundred miles or more, and it was deeply creased where now we see the peculiarly elongated lakes of New York, and cut through in certain gaps, to the valley of the Delaware. In Ohio the erosion was easier and carried farther south. The barrier was also lower, and was finally overtopped by one great lobe of ice, which flowed on to the south and west until its edge reached the Ohio River. . . .

With the amelioration of the climate the wide-spread ice-sheets of the period of intensest cold became again local glaciers, which completed the already begun work of cutting out the lake-basins. At first, the glacier which had before flowed over the water-shed in Ohio was so far reduced as to be unable to overtop its summit; but, deflected by it, it flowed along its base, spending its energies in cutting the shallow basin in which Lake Erie now lies.

A further elevation of temperature curtailed the glacier still more, and Lake Erie became a water-basin, while local glaciers left from the ice-sheet excavated the basins of Lake Michigan, Lake Huron, and Lake Ontario. The latter lake was apparently formed by the same glacier that made the Erie basin, but when much abbreviated. It flowed from the Laurentian Hills and the north slope of the Adirondacks, and was deflected by the highlands south of the lake-basin, so that its motion was nearly westward. This chapter in the history of our lakes was apparently a long one, for Lake Superior, Lake Michigan, Lake Huron, and Lake Ontario are all of great depth.

The melting of the glaciers was accompanied, perhaps occasioned, by a sinking of the continent, which progressed until the waters of the Atlantic flowed up the valley of the St. Lawrence to Kingston, and up the Ottawa to Arnprior (Dawson). The valleys of the St. Lawrence and the Hudson were connected by way of Lake Champlain, and thus the highlands of New England were left as an island. It is also possible that the sea-water penetrated to the lake-basin through the valley of the Mohawk and through that of the Mississippi, but of this we have no evidence in the presence of marine fossils in

the surface deposits. The great area of excavation in which the lakes lie was probably at this time filled to the brim with ice-cold fresh water; and this, flowing outward through all the channels open to it, may have been sufficient to prevent the entrance of the arctic marine mollusks, of which the remains are so abundant in the Champlain clays of the St. Lawrence Valley and the Champlain basin.*

Lakes caused by glacial dams are of two classes: 1. Those produced by the irregular deposition of moraine material; 2. Those caused by the ice itself during the period of its continuance. The first of these classes may also be profitably subdivided into—(1) Those caused by deposits which have closed up old water-courses; (2) Those caused by deposits producing complete inclosures of the nature of kettle-holes.

Making the last class the first subject of consideration, we note that by far the larger number of the small lakes which diversify the glaciated region occupy the basins of kettle-holes. When treating of terminal moraines and kames, kettle-holes were spoken of as one of the prominent features characterizing these deposits, and the origin of the smaller ones at least was said to be due to the melting away of masses of ice which had from time to time been covered by the earthy *débris* which accumulates near the front and along all the great lines of drainage of extensive glaciers. Protected for a while by this *débris* from melting, these masses of ice first begin to disappear around the exposed edges of their sides, allowing the sand, gravel, and pebbles to be heaped up about their bases, so that, upon the final disappearance of the ice, an inclosure is left, varying in size, shape, and depth according to the extent of the ice-mass inclosed. Many of these kettle-holes are dry throughout the larger part of the year, since they are above the general level; and the surrounding material of the rim is so coarse, that, even after long-continued rains, the water remains in

* "Geology of Ohio," vol. ii, pp. 77–79.

them but a short time; while others, whose bottom is below the general surrounding water-level, or whose rims chance to be of more compact material, retain a small amount of water during the most of the season, or throughout the entire year. In innumerable cases peat has accumulated in the bottom of these, and filled up a considerable portion of the lower part of the cone-shaped depression. It is thus that nearly all the peat-bogs of New England and the Northwest have originated. In numerous cases the peat forms a rim about the edge at the water-level, while in the deeper portion the surface of the clear water looks up from the shadows, or reflects the sunshine like the pupil of a gigantic eye. In respect to these glacial lakes partially surrounded by accumulations of peat, one almost uniformly finds local traditions that they are without bottom, or at least that no one has been able to find it. The fact is, however, that they are none of them of great depth; but the soft ooze of muck and mud which accumulates at the bottom renders sounding impracticable, and thus originates the illusion of unfathomable depths.

The lakes and bogs of Ireland present familiar examples of this class of glacial inclosures; while in this country one can not easily run amiss of them, either in New England or the Northwest. The southeastern portion of Massachusetts abounds in them in special degree. As before remarked, Plymouth county is little less than a ganglion of such glacial lakes with their inclosing deposits—Plymouth township alone being reputed to have three hundred and sixty. They appear all along the line of the terminal moraine, often capping its very summit in the western portion of Long Island, even within the limits of the city of Brooklyn.

As shown in a previous chapter,* the Elizabeth Islands consist of a network of deposits surrounding such depressions; but in this case, as frequently elsewhere, the rims are of such coarse material that most of the depressions are dry.

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* See p. 205.

All the lines of the kame deposits in Maine, New Hampshire, and Massachusetts are marked by the frequent occurrence of lakes and dry depressions of this description. "Tight Pond," the name of one in the vicinity of Conway, N. H., is suggestive of its character. The resemblance so often noted by tourists between the scenery of Michigan and that of large portions of Ireland is produced by the preponderance in both regions of this class of lakelets. The innumerable lakes of Wisconsin and Minnesota had a similar origin, and are limited chiefly to the tortuous line of the great Kettle Moraine, heretofore described as being so marked a feature in the topography of the country between Lake Michigan and Dakota.

It was a long time before the true origin of these lakelets in the Northwest was suspected. But no sooner was Mr. Upham set to survey the field in Minnesota, than, with his knowledge of the glacial phenomena of New England, he detected their character, and at once adopted a provisional hypothesis by which he successfully and economically directed his future glacial investigations in the State. The lakelets and dry depressions above Minneapolis, including even Lake Minnetonka itself, he perceived to be kettle-holes, such as characterize the terminal moraine on the southern shore of New England, and at once inferred that the moraine in that State would be found running along the curved lines formed by these lakelets, as laid down upon the maps by the topographical surveyors. There was a belt of such lakelets running a little west of north from Minneapolis, between the valley of the upper Mississippi and that occupied by the Minnesota and the southern part of the Red River of the North. In the vicinity of Minneapolis there was also a peculiar enlargement of this area of lakelets, whence it extended into northern Iowa, but, for a width of sixty or seventy miles, and a length of two hundred and fifty or three hundred miles up and down the Minnesota Valley, there was a striking absence of lakes upon the maps. They reappeared again, however, to the west, in a line nearly par-

allel with the first one described, and extended through the Coteau des Prairies of eastern Dakota. A single season's work was sufficient amply to verify Mr. Upham's hypothesis, and all subsequent investigation has confirmed it, proving that there was an independent movement of ice down the Minnesota Valley, pushing its lobate front far into the State of Iowa, and some distance beyond the part reached at that time by the general mass on either side. About this lobate margin a vast moraine was built up, whose irregular deposits formed the inclosures containing the lakelets of that region. Over the intervening area, for a width of seventy miles, there is little left but the ground moraine, which is uniform in character, and from which the ice melted so rapidly that there was no chance for the formation of lakelets such as characterized the margin where the ice-front remained during the larger part of the period.

Another class of glacial lakes is due to dams of glacial *débris* such as were spoken of in a preceding chapter. The lakes of this class are not so numerous as the former, but present a greater variety of problems for investigation. To appreciate this part of the glacier's work, we must bring again to mind the extent to which erosion had proceeded before the Glacial period began. As already detailed, the vast extent of preglacial erosion is apparent at once upon entering the unglaciated region upon the western flanks of the Alleghany Mountains, where all the rivers occupy narrow troughs of erosion, hundreds of feet deep, and extending to the very sources of the streams. There are, over that unglaciated region, few if any waterfalls, simply because the recession of the cataracts which once existed has in most cases proceeded so far that the streams have completed their work, and have already cut their channels through to their extreme limit. The State of Ohio is a portion of the Appalachian uplift, and its surface, for the most part, is more than a thousand feet above the sea. The southeastern part of the State is unglaciated, and is characterized by the freedom

from waterfalls, and that depth and extent of the eroded valleys, which would naturally result from the prolonged continuance of water-action. On the contrary, the glaciated portion of the State presents a surface in the main remarkably free from the effects of prolonged water-erosion. The northern and western portions of the State belong practically to the great prairie region of the interior.

None know just where the old outlet to Lake Winnepesaukee in New Hampshire is; but, from the nature of the situation and the analogies of the case, there can be no doubt that it, together with the most of the larger lakes of New England, is held in place by deposits of glacial material filling up an old outlet. Doubtless, with comparatively little labor, trenches might be dug which should, when not below the ocean, drain them all to the bottom. There can be no doubt, also, that Lake Champlain and Lake George are held in their elevated positions by similar glacial dams, and such is certainly the case with many of the numerous lakes which dot the glaciated region of northern New Jersey. To a similar origin is due the remarkable series of parallel lakes in central New York, having at the present time a common outlet in the Oswego River. Chautauqua Lake, now flowing over a rocky bed past Jamestown into the Alleghany, is one of the most elevated of this class of glacial lakes, being held in place by a vast glacial deposit filling up the mouth of an old outlet into Lake Erie.

The evidence that Lake Erie is caused by the damming up of the old outlet of the valley by glacial *débris*, has already been presented, and the importance of this fact will appear when we come to discuss the date of the Glacial period.

But, interesting as are these more permanent dams of the Glacial period, they must yield supremacy to the temporary lakes formed by the ice-barrier itself in its various adjustments to the topography of the country. Travelers in the Grindelwald Alps have their attention frequently directed to the diminutive specimens of such lakes still existing

there. The following accurate and interesting account of them is from the pen of Professor William M. Davis:*

Glacial lakes are now of little importance; a few occur in the higher mountain-chains, but they are trifling in size, and rank with many other species only as curiosities unless they become of disastrous importance in the valleys below, from the floods that follow a giving way of their barriers. Three subspecies are easily distinguished: First, when the advance of a glacier down a main valley closes the mouth of a lateral ravine; second, when a glacier from a side valley obstructs the main stream; third, when the great ice-sheet of early Quaternary times melted away so as to disclose the upper part of a valley sloping gently against it.

The Merjelen See in Switzerland serves as the type of the first subspecies; it is held back by the Great Aletsch Glacier in a little valley behind the Eggischhorn, a favorite point of view, from which the lake below and the whole stretch of the ice-stream in the main valley can be seen. Sometimes the waters find an outlet through the ice-barrier; then the slow accumulation of months rushes out in a torrent, flooding the valley of the Massa below, and leaving miniature bergs broken from the glacier stranded on the rocky bottom; subsequently, another motion of the glacier closes the outlet, and the basin slowly fills again. The highest level of such a lake will be determined either by free escape across the ice, when it will have a variable maximum, or by flow over a pass at the head of its lateral valley. The latter is the case with the Merjelen See, and the level of the pass is marked by a faint terrace and by a change of color on the rocks around the shore.†

Although rare at present, these lakes have had a considerable importance in the past. An extinct example was early recognized by Agassiz at the Parallel Roads of Glen Roy, near Ben Nevis, in Scotland:‡ these are simply the shore-line

* "Proceedings of the Boston Society of Natural History," vol. xxi, pp. 350, 351.

† L. Agassiz, "Études sur les Glaciers" (1840), pp. 218, 220. Lyell, "Principles of Geology," vol. i, p. 372; "Antiquity of Man," p. 309.

‡ Agassiz, "Geological Society Proceedings," vol. iii, 1842, p. 331; here described as a lateral glacier closing the main valley.

terraces of an old ice-barrier lake, the uppermost standing at the height of the pass into the next glen, but the cause of the others is not so apparent;* the glacier which served as a barrier has long since disappeared, with all its Scotch companions.

The Mattmark See, representing the second subspecies, is in the Saas valley, between Monte Rosa and the Rhône, where the Allalin Glacier advances across the main valley bottom.† It differs from the preceding only in the relative position of lake and barrier, and in the lake's level always being determined by flow over the ice or its moraine. The Lac du Combal is in the same way held back by the Glacier de Miage at the southern base of Mont Blanc. Several temporary Swiss lakes of this construction have caused great damage by bursting through their barriers. A famous case is that of the Gietroz Glacier in the valley of Bagnes, south of Martigny, in 1818. The lake grew to be a mile long, seven hundred feet wide, and two hundred deep. An attempt was made to drain it by cutting through the ice, and about half the water was slowly drawn off in this way; but then the barrier broke, and the rest of the lake was emptied in half an hour, causing a dreadful flood in the valley below.‡ In the Tyrol, the Vernagt Glacier has many times caused disastrous floods by its inability to hold up the lake formed behind it.# In the northwestern Himalaya, the upper branches of the Indus are sometimes held back in this way. A noted flood occurred in 1835; it advanced twenty-five miles in an hour, and was felt three hundred miles down-stream, destroying all the villages on the lower plain, and strewing the fields with stones, sand, and mud.‖

* Lyell, "Antiquity of Man," p. 300. A good bibliography of this old lake is given by W. Jolly, in "Nature," May 20, 1880, p. 68.

† Heliotypes of this and the Merjelen See are given in "Glaciers," by Shaler and Davis, Boston, 1881.

‡ Lyell, "Principles," vol. i, p. 348. "Bibliothèque Universelle de Genève," vol. xxi, 1827, p. 227; vol. xxii, p. 58; vol. xxv, p. 24, etc.

\# Sonklar, "Die Oetzthaler Gebirgsgruppe," Gotha, 1860, p. 154. Stotter, "Die Gletscher des Vernagtthales in Tirol und ihre Geschichte," Innsbruck, 1840, p. 15.

‖ H. Strachey, "Royal Geographical Society Journal," vol. xxiii, 1853, p. 55. Compare Drew, Jummoo, and Kashmir.

Mr. J. E. Marr, in recording his observations upon the Jakobshavn Glacier, gives the following account of the glacial dams connected with it:

The Jakobshavn Glacier stops up both ends of a valley, running parallel with its course, converting it into a lake, which is separated from the glacier throughout the greater part of its length by a *nunatak*.* The lower end of another valley considerably to the south of this is stopped by the ice-sheet, and the valley converted into a lake (Tasersiak), which is drained by a river running over the *col* at the head of the valley into the Strom Fiord, just as in the case of the Merjelen See, only the Greenland lake is much larger than this. A similar lake drains into the North Isortok Fiord, and another into that of Alangordlia. Two similar lakes are formed to the east of Sermilik Fiord, and several small ones to the east of Björnesund. North of the Frederikshaab Glacier is a valley running north and south, the mouth of which is stopped by the Frederikshaab Glacier, while a tongue of ice flows through a *col* situated half-way up the valley and bars the valley, one part of the tongue of ice flowing a small distance to the north and another to the south, thus causing the conversion of the valley into two lakes. On the east of the Frederikshaab Glacier is the Lake Tasersiak, bounded on the north by the *nunatak* Kangarsuk, and stopped at its lower end by the Frederikshaab Glacier, and having a tongue of the ice-sheet entering into it at the upper end.†

With these facts concerning existing glacial dams in mind, we are prepared to study the signs of similar obstructions, on a larger scale, which occurred during the progress of the Glacial period. We will first present the facts relating to a supposed obstruction by glacial ice, of the Ohio River at Cincinnati.

In the summer of 1882, after having the previous year completed, with Professor Lewis, the exploration of the gla-

* See p. 79.

† "Geological Magazine" for April, 1887, quoted in the "American Journal of Science," vol. cxxxiv, 1887, p. 313.

cial boundary through Pennsylvania, I continued the work through the State of Ohio, and traced the line at length to the Ohio River, near Ripley, about sixty miles above Cincinnati. From this point, for about thirty miles down the river, to the vicinity of New Richmond, the glacial boundary lies upon the north bank of its trough; till, bowlders, and scratched stones being found on the highlands down to the extreme margin on the north side, but being absent from the corresponding highlands on the Kentucky side. Near Point Pleasant, the birthplace of President Grant, the river makes a long bend to the north, continuing in this direction to Cincinnati, and thence westward to North Bend, the home and burial-place of President William Henry Harrison; here it turns south again, thus forming in Kentucky a peninsula, as it were, pointing to the north, and including the territory of Campbell, Kenton, and Boone counties. Upon examining this district it was found that in places in Campbell county, and over the whole northern and western parts of Boone county, there were true glacial deposits on the highest lands, the elevation near Burlington being five hundred and fifty feet above low-water mark at Cincinnati. In places, large numbers of bowlders of northern origin were found stranded on the very summit-level of the region—i. e., on the divide, between the short streams running north and those running south, and between the Licking and the Ohio River. They were also found south of this secondary divide, seven miles back from the river, and five hundred feet above it (near Florence, Boone county). Several were recognized as belonging to a species of red jasper conglomerate, whose outcropping is well marked on the northern shore of Lake Huron and about the outlet of Lake Superior. These bowlders are very beautiful; and, farther north, where they are more abundant in the fields, are frequently used to adorn the front-yards of residences or even for the construction of public buildings. Some of the citizens of Cleveland, Ohio, have brought large fragments for this purpose from the parent ledges. But here, beside a roadway through the Ken-

tucky hills, were large specimens of this same conglomerate (one bowlder being nearly three feet in diameter), which had been transported by glacial ice fully six hundred miles from their native bed, and left to tell the story not only of their own travels, but of other most interesting events connected with the cause which transported them. These glacial deposits south of the Ohio are such as to make it certain that the front of the continental glacier itself pushed, at some points, seven or eight miles beyond the Ohio River; and it is altogether probable that for a distance of fifty miles (or

FIG. 108.—Conglomerate bowlder found in Boone County, Kentucky. (See text.)

completely around the eastern, northern, and western sides of the Kentucky peninsula formed by the great bend of the river), the ice came down to the trough of the Ohio, and crossed it so as completely to choke the channel, and form a glacial dam high enough to raise the level of the water five hundred and fifty feet—this being the height of the watershed to the south. The consequences following are interesting to trace.

The bottom of the Ohio River at Cincinnati is 432 feet

Fig. 109 Map showing the effect of the glacial dam at Cincinnati (Claypole). (From "Transactions of the Edinburgh Geological Society.")

above the sea-level. A dam of 568 feet would raise the water in its rear to a height of 1,000 feet above the tide. This would produce a long, narrow lake, of the width of the eroded trough of the Ohio, submerge the site of Pittsburg to a depth of 300 feet, and make slack water up the Monongahela nearly to Grafton, W. Va., and up the Alleghany as far as Oil City. All the tributaries of the Ohio would likewise be filled to this level with the back-water. The length of this slack-water lake in the main valley, to its termination up either the Alleghany or the Monongahela, was not far from one thousand miles. The conditions were also peculiar in this, that all the northern tributaries head within the southern margin of the ice-front, which lay at varying distances to the north. Down these northern tributaries there must have poured during the summer months immense torrents of water to strand bowlder-laden icebergs on the summits of such high hills as were lower than the level of the dam.

The facts leading to this conclusion, together with the theory itself, were first published by me in the "American Journal of Science" for July, 1882.* At the conclusion I added that "it remains to be seen how much light this may shed upon the terraces which mark the Ohio and its tributaries in western Pennsylvania." Soon after this I received from Professor I. C. White, of Morgantown, W. Va. (whose long experience and careful work upon the Pennsylvania Geological Survey has made his name a synonym for accuracy of observation and skill in drawing conclusions), a letter stating that the theory of an ancient ice-dam at Cincinnati was the key to unlock what had heretofore been a great puzzle to the Pennsylvania geologists. Briefly told, the progress of the discovery and discussions concerning it are as follows:

On all the upper tributaries of the Ohio there are high-level terraces in abundance which the local geologists could with difficulty explain. Upon comparison, however, an important portion of the series was found to have very nearly

* "American Journal of Science," vol. cxxvi, pp. 1–14.

the same absolute elevation above the sea-level with that of the assumed top of the glacial dam at Cincinnati. At my request, Professor I. C. White prepared a paper to be read at the meeting of the American Association for the Advancement of Science at Minneapolis in the summer of 1883. In this paper the facts concerning the terraces in the valley of the upper Ohio were set forth, together with their bearing upon the existence of the supposed glacial dam. The Minneapolis meeting was remarkable for the number of distinguished geologists present who had given special attention to glacial phenomena. Among them was Professor Lesley, who has been for so many years the organizing mind of the Pennsylvania Geological Survey. When the subject of the Cincinnati ice-dam was brought up by the reading of Professor White's paper, Professor Lesley at once gave his adhesion to the theory, and frankly stated that what he had written some years before in explanation of the terraces in western Pennsylvania was entirely superseded. He had then, in order to account for the terraces, resorted to the hypothesis of a general subsidence of the region to the extent of several hundred feet. But later he had himself perceived the inadequacy of such an hypothesis, since there were not, as upon this supposition there should be, corresponding terraces upon the east side of the Alleghany Mountains. He had therefore expressed the belief that some local obstruction would be discovered in the lower part of the Ohio which would account for the facts. "And now," said he, "Providence has provided one, and Wright's dam will explain it all," and went on to show that the absence of similar terraces on the east side of the mountains was fatal to the theory of a continental subsidence, while it was just what would be expected on the theory of an obstruction of the drainage of the upper Ohio.

A theory of such wide significance is not, however, to be too hastily accepted, and much attention has since been directed toward its verification or disproval.

In presenting the evidence upon this subject it is well to remark that the study of river terraces brings to light a com-

plex action of forces often difficult to unravel, and peculiarly liable, in a case like this, to lead one astray. Hence it is probable that a part of the testimony in favor of the Cincinnati ice-dam, drawn at first from the terraces of the upper Ohio, was irrelevant, since some of the terraces were doubtless due to the natural progress of river-erosion. For example, where streams flow down from the flanks of a mountain-chain, and have considerable opportunity to deepen their channels, they leave gravel deposits at various levels, and occasionally abandon some portion of their old bed to occupy a shorter and deeper cut-off. Upon examination of the Monongahela and its branches, it would seem that several of the terraces at first attributed to the effect of the glacial dam at Cincinnati were formed in the manner thus indicated, or *may* have been so formed. In this case their remarkable correspondence with the height of the supposed obstruction at Cincinnati is one of those accidental coincidences that are often met with in nature. After eliminating, however, all such cases, there remains a constantly increasing residuum of facts which fairly refuse to be explained, except on the theory supposed.

Beginning with one of the clearest cases, attention is directed to the head-waters of Brush Creek, in Pike county, Ohio. By reference to the accompanying map it will be seen that at the height of the Glacial period the front of the ice rested at the northwest corner of this county. A more accurate study of the details shows that the divide between Paint Creek and Baker's Fork of Brush Creek is formed by the extreme portion of the terminal moraine. Before the Glacial period there was a continuous depression connecting Paint Creek with the valley of Brush Creek. At a point about five miles south of Bainbridge, on Paint Creek, in Ross county, this depression is filled up, from side to side, to a height of about two hundred feet, with a glacial deposit containing numerous northern bowlders and scratched stones. On the northern side, toward Paint Creek, this deposit exhibits every mark of a terminal moraine, with its character-

istic knobs, ridges, and kettle-holes; while to the south of it there is an extensive plain known in the locality as the Beech

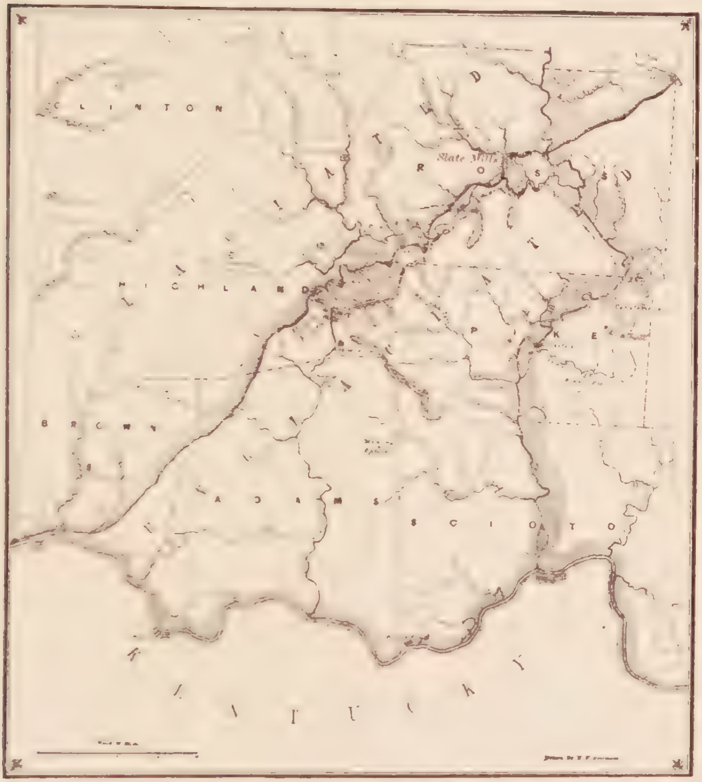

FIG. 110.—Map of a portion of the glacial boundary in southern Ohio, showing its relation to Paint Creek cut-off and to Beech Flats, at the head-waters of Ohio Brush Creek. The general elevation of the unglaciated region is from three hundred to five hundred feet above the river-bed. The terraced valley of the Scioto River is approximately indicated by the dotted line. The old valley of Paint Creek, now choked up by glacial *débris*, ran around by Slate Mills. The small stream coming in at the angle of the cut-off is the one from which an estimation of time is made in chapter xx, page 561.

Flats. This, too, consists largely of transported material from the north; but it is mostly fine like loess, and level topped, and is about one hundred feet higher than the valley of Baker's Fork, which heads in it and runs to the south, emptying into the Ohio River.

It is evident that, while the ice-front rested over the northwestern portion of Pike county, and was depositing the terminal moraine just described, there ought to have been, during the whole time, a strong current of glacial drainage rushing down through Baker's Fork into Brush Creek, depositing more or less of overwash gravel along its bed. But there are no marks of such a line of glacial drainage here. There are no terraces on Baker's Fork; and no granitic pebbles are to be found in its valley, where they ought to exist in great numbers if there had been a glacial torrent pouring into it from the terminal moraine. The uniformity with which these lines of glacial drainage are marked by terraces, and by the presence of northern pebbles gathered from the glaciated region, is, as we have already seen, one of the most striking features just outside the glaciated region all the way from the Atlantic Ocean to the Mississippi River. For the exception in the present instance there would seem to be but one explanation, and that is as complete as it is unexpected. The ice-dam in the Ohio River, supposed on other evidence to have been in existence for a short time at the climax of the Glacial period, perfectly accounts for this exceptional phenomenon, while no other adequate cause whose existence is at all probable can be found. The explanation is as follows:

The height above the tide of this moraine, which closes up the opening between Paint and Brush Creeks, is between nine hundred and a thousand feet, corresponding very closely with the supposed height of the water-level produced by the ice-dam at Cincinnati. Hence, during the existence of the dam, there would have been no chance for the formation of a glacial torrent down Brush Creek, since back-water extended to the very ice-front at its head, and the terminal deposit was laid down in still water. The limitations of this deposit at the head of Baker's Fork and the level surface of Beech Flats, therefore, furnish a complete verification of the theory, and prove beyond question the reality of the Cincinnati dam.

Furthermore, the lower portion of Paint Creek is so situ-

ated with reference to the glacial boundary that its mouth was for a time obstructed by the ice; but, when the ice-front had withdrawn two or three miles, drainage would again be opened into the Scioto, and at a level which is a hundred feet or more lower than the surface of the moraine between Paint and Brush Creeks, so that the natural necessity for a glacial outlet down Brush Creek would exist only so long as the ice closed up the mouth of Paint Creek. From this description of the situation it becomes evident that, so soon as the ice should have retreated from the Kentucky hills south of Cincinnati, so as to raise the blockade and reopen the channel of the Ohio, it would doubtless also have retreated from the mouth of Paint Creek; and the line of glacial drainage through that into the Scioto, and thence down the reopened Ohio, would have been re-established.

A theory which so naturally accounts for so complicated a set of facts as these is well-nigh proved by this single instance. The only competing hypothesis possible is that of a general subsidence of the country producing the same water-level above Cincinnati which the ice-dam is supposed to have done. But such a theory lacks the positive evidence adducible for a glacial dam at Cincinnati; and, besides, it is not probable that a general depression of the country, such as would produce still water at the head of Brush Creek, would be of such short duration as is implied by the facts connected with this deposit. The gradual lowering of a barrier holding the water at that height would have caused numerous benches on the interior of the deposit toward the ice, whereas the terrace on that side is even more abrupt than on the other.

A second class of facts supporting the theory of the Cincinnati ice-dam is drawn from the high level terraces found in the trough of the upper Ohio and its main tributaries. One of the most significant of these occurs at Bellevue, on the north side of the Ohio River, five miles below Pittsburg, where a terrace is found about a mile long, half a mile wide, and fifty or sixty feet in depth, preserved upon a shelf of rock facing the river perpendicularly, and between two hundred and

fifty and three hundred feet above it. The material of this high-level terrace consists largely of gravel and pebbles derived from the glaciated region, granitic pebbles being abundant in it. It must therefore have been deposited since the ice came over into the head-waters of the Alleghany. Two theories are offered to account for this: One assumes the reality of the ice-dam at Cincinnati, and sees in this terrace a natural result of that obstruction. Bellevue lies in the lower angle formed by the junction of the Ohio and Alleghany Valleys; and the summit of the terrace under consideration corresponds closely in altitude with the elevation of the Cincinnati dam; and here, in the eddy below the mouth of the Alleghany, at the beginning of the larger valley of the Ohio, was the natural place for the accumulation of bowlder-laden masses of ice brought down from the glacier's front by the periodical floods of the Alleghany.

If we leave the theory of general submergence out of account, the only other way to explain this accumulation is to regard it as a portion of a deserted river valley when the stream occupied a rocky bed more than three hundred feet above its present level. This would require a lapse of time, since the deposit was made, sufficient to allow the Ohio and all its tributaries to lower their rocky beds, for many hundred miles, to a depth of more than three hundred feet. As we shall see, later on, it seems to be entirely out of the question to suppose any such lapse of time since the last glacial period, for the Niagara gorge has receded only seven miles since then. But resort may be had to the supposition of a previous glacial period, during which the ice also came over into the head-waters of the Alleghany, and, indeed, everywhere came down nearly to the limits of the glaciated region in Pennsylvania and Ohio already delineated. On this supposition the time intervening between the first and the last glacial period would be equal to that required by the Ohio and its tributaries to lower their rocky beds at least three hundred or four hundred feet. This enormous lapse of time would carry us back, in all probability, well-nigh to the be-

ginning of the Tertiary period. But, that no such length of time can have elapsed since these upper terraces were deposited, may be inferred from their structure and situation in various other places. For example, vegetable and animal remains of recent species are found in a very fresh state of preservation in river deposits of the Ohio Valley corresponding in age with the terraces in question.

The first instance of this to be mentioned is one which has been carefully investigated and described by Professor I. C. White, and occurs on the Monongahela River, near Morgantown, W. Va. The trough of the Monongahela, which joins the Alleghany at Pittsburg to form the Ohio, is in every way similar to that of the Alleghany, with the single exception that the terraces which line its banks at heights corresponding to those of the Alleghany and upper Ohio, contain no pebbles of northern drift, but consist wholly of material which is native to the valley itself. At numerous places along the Monongahela there are extensive deposits of pebbles and bowlders from two hundred to three hundred feet above the river, especially near where tributaries enter. In many of these deposits there is nothing to indicate their age; but, at Morgantown, W. Va., there would seem to be a decisive case, showing the comparatively recent date of the deposition of this series of terraces. The following is Professor White's description:

Owing to the considerable elevation—275 feet—of the fifth terrace above the present river-bed [in the vicinity of Morgantown], its deposits are frequently found far inland from the Monongahela, on tributary streams. A very extensive deposit of this kind occurs on a tributary one mile and a half northeast of Morgantown; and the region, which includes three or four square miles, is significantly known as the "Flats." The elevation of the "Flats" is 275 feet above the river, or 1,065 feet above tide. The deposits on this area consist almost entirely of clays and fine, sandy material, there being very few bowlders intermingled. The depth of the deposit is unknown, since a well sunk on the land of Mr. Baker passed through

alternate beds of clay, fine sand, and muddy trash to a depth of sixty-five feet without reaching bed-rock. In some portions of the clays which make up this deposit, the leaves of our common forest-trees are found most beautifully preserved. Whether or not they show any variations from the species growing in that region, the writer has not yet had time to determine; but, when a larger collection has been obtained, this subject will receive the attention that it deserves, since, if the date of the Glacial epoch be very remote, the species must necessarily show some divergence from the present flora.

Of animal remains the only fragments yet discovered in this highest of the terraces is the tooth of a mastodon, dug up near Stewartstown, seven miles northeast from Morgantown.

As the relation of this deposit near Morgantown to others farther up the river is important, we quote also from the supplementary statement of facts made by Professor White in a paper presented at the meeting of the American Association for the Advancement of Science at Buffalo, in 1886:

In the region of Morgantown, on the main Monongahela, these terrace deposits end at about 275 feet above low water, or 1,065 feet above tide; while at Fairmount, twenty-six miles above, there is a vast amount of this terrace material thrown down about the junction of the Valley and West Fork Rivers, and the upper limit of the same is a little over two hundred feet above low water, which is here 850 feet above tide. About twenty miles farther up the river (West Fork), near Shinnston, the upper limit of the terrace material is found at 160 feet above the water, but here the latter has an elevation of about 885 feet above tide.

At Clarksburg, where the river unites with Elk Creek, there is a wide stretch of terrace deposits, and the upper limit is there about 1,050 feet above tide, or only 130 feet above low water (920 feet); while at Weston, forty miles above (by the river), these deposits cease at seventy feet above low water, which is there 985 feet above tide. It will thus be observed that the upper limit of the deposits retains a practical horizontality from Morgantown to Weston, a distance of one hundred miles,

since the upper limit has the same elevation above tide (1,045 to 1,065 feet) at every locality.

These deposits consist of rounded bowlders of sandstone, with a large amount of clay, quicksand, and other detrital matter. The country rock in this region consists of the soft shales and limestones of the upper coal-measures, and hence there are many "low gaps" from the head of one little stream to that of another, especially along the immediate region of the river; and in every case the summits of these divides, where they do not exceed an elevation of 1,050 feet above tide, are covered with transported or terrace material; but where the summits go more than a few feet above that level we find no transported material upon them, but simply the decomposed country rock.

A fine example of one of these bowlder-covered divides may be seen at the mouth of the Youghiogheny River, back of McKeesport, Pa. The "divide" in question is one between the water of Long Run, which puts into the Youghiogheny, two miles above McKeesport, and that of another little stream which heads up against it, and flows into the Monongahela within the city limits. The divide between these two waterways, although 275 feet above the level of the river, is almost imperceptible in a broad and bowlder-covered valley through which there is not the slightest doubt that the waters of the Youghiogheny once flowed during an epoch of submergence.*

Passing farther down the Ohio Valley, we find a most interesting exhibition of this high-level slack water deposition in Teazes Valley, Putnam county, W. Va. This valley runs from the Kanawha River, a little below Charleston, to the Ohio at the mouth of the Guyandotte, near Huntington. The valley is clearly enough a remnant of the early erosion which sculptured the whole country. The water of the upper Kanawha evidently at one time took this course to the Ohio. The valley is very clearly marked, and its main features can be taken in by any one riding over the Chesapeake and Ohio Railroad between Huntington and

* "American Journal of Science," vol. cxxxiv, 1887, pp. 378, 379.

Charleston. It is about a mile wide, and from two hundred to three hundred feet lower than the hills on either side, and

FIG. 111.—Section of the deposit at Long Level, in Teazes Valley, West Virginia. The buried piece of wood referred to in the text was about the middle of the cut on digging into the perpendicular face of the bank.

has a remarkably level floor throughout the greater part of its course. The bottom of the valley is filled throughout

with a deposit of river-pebbles covered many feet deep with a mixture of sand and clayey loam. In some places this loam is from thirty to forty feet deep, extending for several miles without interruption, as at Long Level, about the middle of the valley. Here a section, about half a mile long and twenty-five feet deep, shows at the top a stiff stratum of clay containing wood at a depth of seven feet. Immediately below is sand cemented together by the infiltrations of iron. The stratum above, containing the wood, had never been disturbed, and the wood is remarkably fresh in its whole appearance. It is scarcely possible that it should have remained in such a position during all the time required for the erosion of the Ohio Valley and its tributaries from the level of Teazes Valley to its present level, two hundred and fifty feet below. Besides, there are many other things to show that the deposit was in slack water rather than on the flood-plain of a running stream. Unlike the deposit of a river on its banks, in this case the silt extends clear across the valley, covering everything to a uniform depth, except where it has been removed by subsequent irregular erosion.

Another evidence of the recent date of this deposit of river-silt in Teazes Valley, as compared with the erosion of the valley itself, appears in the relation of the transverse water-ways to it. Mud River and Hurricane Creek are two small streams rising some little distance to the south, but now either joining the valley, or crossing it at a level sixty or seventy feet lower than that of its rocky bottom. Mud River joins it at Milton, and then turns west and follows its course to the Guyandotte. But the level of Mud River, even where it now joins the valley, is one hundred and twenty feet lower, and this in a channel worn in the solid sandstone rock. Hurricane Creek is a still smaller stream, and crosses the valley within a few miles of its eastern end, emptying into the Kanawha some miles lower down. Where this small stream crosses Teazes Valley its bed is sixty or more feet lower down in the rock than that on which the pebbles and silt rest throughout the valley, and these de-

posits come down on the rocky shelf bordering the Hurricane in a way to show that it could not have remained where it is during the time required for so small a stream to wear down so large and deep a channel.

The extension of Teazes Valley, after merging for a short distance with the Ohio, really continues back of Ashland, Ky., on the south side of the river, down as far as opposite Hanging Rock in Ohio, in all a distance of about sixty miles.

Among other decisive instances discovered by Professor White, and bearing on the recent date of these high-level terrace deposits, are the following:

About ten miles above the mouth of the Big Sandy River, and on the West Virginia side, a considerable deposit of small water-worn bowlders occurs near the summit of a broad, flat-topped hill, at an elevation of four hundred feet above the stream, or not far from nine hundred feet above tide. This deposit is interesting from the fact that it is the only one that I was able to find between the point in question and the source of the river, nearly two hundred miles above, though the failure may be satisfactorily accounted for in the precipitous character of the bounding valley-walls, and the unusually soft and easily disintegrating nature of all the surface-rocks: for along the Big Sandy even the Pottsville conglomerate becomes rotten, and very readily crumbles into loose sand, which, carried down by the rain, fills up the channel of the river, and has thus given name to the stream. It is not assuming to state that these rounded bowlders of local coal-measure sandstone could hardly have resisted the elements during the long time since the Big Sandy Valley existed at this 400-foot level.

The Guyandotte River puts into the Ohio next above the Big Sandy, and on this stream, about one hundred miles above its mouth, a large deposit of rounded bowlders was observed on the inner side of one of its great curves opposite the mouth of Panther Creek. The bowlders cease at 150 feet above the stream, or about 925 feet above tide, according to levels run by Captain Miller, of the Trans-Flat Topland Company. The bowlder-deposits are found in greatest quantity about the

junction of streams, and consequently at the mouth of Elk River, on the Great Kanawha, in the vicinity of Charleston, vast numbers of them extend to near 250 feet above this river (800 feet above tide), and scattering ones are found up to 390 feet (or 945 feet above tide). Here, along with the hard rocks of local origin, we find great numbers that have come from the Blue Ridge in Virginia and North Carolina, nearly two hundred miles distant.

I shall not be surprised if some of my readers regard this theory of an ice-dam at Cincinnati as visionary; and, indeed, I do not myself present it as established with the same degree of certainty with which the more general facts relating to the Ice age are established. Still, I am confident that close reflection upon the evidence already presented will be sufficient to produce conviction to most minds. The bowlders found south of the Ohio River, opposite Cincinnati, are too large to have been carried except by ice, and they are so high above the river, and so far back from it, that floating ice could not have been the agent of transportation, except the channel itself were obstructed. Nor is there any improbability arising from the nature of the case against such an obstruction by ice. For, through a distance of nearly fifty miles, the ice certainly came down to the northern side of the trough. In much broader valleys than this the ordinary ice-gorges during a spring freshet produce remarkable results, raising the water to a great height. But the course of the Ohio at Cincinnati is such as to invite gorges upon the largest scale; and, with a moving ice-front behind, a permanent closure is not improbable. If one should surmise that a depth of five hundred feet of water would lift the ice in the channel so as to secure a subglacial outlet, it should be remembered that the specific gravity of ice is such that it would require more than a depth of six hundred feet of water to lift a body of ice which was seven hundred feet thick; and the bowlders on the south side of the river are so far distant, the one of which we give a cut being seven or eight miles south of the river, that the ice was doubtless

considerably more than a hundred feet above the top of the trough at Cincinnati.

Bringing to mind the other considerations, we think no one can doubt that the trough of the Ohio was mainly formed before the Glacial period. This we infer from the enormous lapse of time during which the river had been at work, viz., from the first elevation of the continent to the earliest date assigned by any to a glacial period in North America. With this trough formed, the problem of accounting for the terrace at Bellevue, below Pittsburg, containing granitic pebbles is a most difficult one, except upon the theory of this ice-dam. The granitic pebbles mark it as connected with the Glacial period, and its height (three hundred feet above the river) renders it impossible of explanation on any other theory than one which assumes an incredible lapse of time since the deposit was made. The small extent to which the material of this terrace has been oxidized and disintegrated, indicates no such enormous lapse of time; while the terraces in the Monongahela River, which Professor White describes as containing freshly preserved leaves at great depths, and the terraces in the neighborhood of the Big Sandy, containing pebbles peculiarly liable to disintegration, confirm the inference of the comparatively recent origin of a series of terraces in the upper Ohio, closely corresponding to the level of the Cincinnati ice-dam. To these considerations, also, are to be added those concerning Beech Flats, between the southwestern angle of Paint Creek and the head-waters of Brush Creek. Altogether this would seem sufficient to give a high degree of probability to the theory, and to justify the wide acceptance which has been given to it by the eminent geologists most familiar with the region.

In presenting this brief summary of evidence bearing on the existence of the Cincinnati ice-dam, however, I am far from considering the discussion of the theory closed. It remains for local observers, first, to comprehend the facts already presented, and then to test the hypothesis in every

legitimate manner possible. The field is a most inviting one, and will assuredly yield abundant fruits.

Among other requirements made upon the theory it has been demanded that I should point out the outlet of the pent-up waters. But this I am not able at present to do. I have had neither the time nor the opportunity to explore the region south of Cincinnati sufficiently to say certainly where it was; nor have I come to a negative conclusion, so that I

[illegible] In Boone County, Kentucky [illegible] one hundred and sixty feet above low water. [illegible]

can say that there is none to be found; nor do I know that any one else has done so. Professor Claypole is inclined to think Mr. Squier * has indicated the locality of the old outlet in some of the passes in the vicinity of Owingsville and Mount Sterling leading from the upper waters of the Licking River into the valley of the upper Kentucky. From

* See letter in "Science," September 28, 1883; for additional facts, see the author's "Glacial Boundary in Ohio, Indiana, and Kentucky," p. 86

Gannet's table of levels, which is very scanty in that portion of Kentucky, it would appear that the height of the water-partings between the Licking and the Kentucky is not greater than that of the ridge running south from Cincinnati between the Licking and the Ohio; so that such an outlet may exist somewhere in that vicinity.

But I have not been sure that the water did not pass around the immediate margin of the ice reaching the Ohio at the mouth of Woolper Creek, about thirty miles below Cincinnati, where the celebrated post-glacial conglomerate known as Split Rock is situated. This formation consists of pebbles now firmly cemented together by infiltrations of lime. The mass rises one hundred and sixty feet above the river. The most of the pebbles are limestone from the Cincinnati group, but there are mingled with them granitic pebbles which show it to be a glacial deposit. On Middle Creek, a little lower down in Boone county, the same conglomerate is found at a still higher level, running up to four hundred feet; and at various places on the road to Big Salt Lick uncemented gravel, which is unquestionably of glacial origin, caps the tops of the hills at about the same height. It is not unlikely, therefore, that much of the outflow from around the dam was in the immediate vicinity of the ice-front.

Professor E. W. Claypole, in an article * read before the Geological Society of Edinburgh and published in their "Transactions," has given a very vivid description of the scenes connected with the final breaking away of the ice-barrier at Cincinnati. He estimates that the body of water held in check by this dam occupied twenty thousand square miles, and that during the summer months, when the ice was most rapidly melting away, it was supplied with water at a rate that would be equivalent to a rainfall of one hundred and sixty feet in a year! This conclusion he arrives at by estimating that ten feet of ice would annually melt from the

* "The Lake Age in Ohio," "Transactions of the Geological Society of Edinburgh," 1887

portion of the State which was glaciated, and which is about twice the extent of the unglaciated portion. Ten feet over the glaciated portion is equal to twenty feet of water over the unglaciated. To this must be added an equal amount from the area farther back whose drainage was then into the upper Ohio. This makes forty feet per year of water so contributed to this lake-basin. Furthermore, this supply would all be furnished in the six months of warm weather, and to a large degree in the daytime, which gives the rate above mentioned.

The breaking away of the barrier to such a body of water is no simple affair. As this writer remarks:

The Ohio of to-day in flood is a terrible danger to the valley, but the Ohio then must have been a much more formidable river to the dwellers on its banks. The muddy waters rolled along, fed by innumerable rills of glacier-milk, and often charged with ice and stones. The first warm days of spring were the harbinger of the coming flood, which grew swifter and deeper as summer came, and only subsided as the falling temperature of autumn again locked up with frost the glacier fountains. . . . The ancient Ohio River system was in its higher part a multitude of glacial torrents rushing off the ice-sheet, carrying all before them, waxing strong beneath the rising sun, till in the afternoon the roar of the waters and their stony burden reached its maximum, and, as the sun slowly sank, again diminished, and gradually died away during the night, reaching its minimum at sunrise. . . .

But, with the steady amelioration of the climate, more violent and sudden floods ensued. The increasing heat of summer compelled the retreat of the ice from the Kentucky shore, where Covington and Newport now lie, and so lowered its surface that it fell below the previous outflow-point. The waters then took their course over the dam, instead of passing, as formerly, up the Licking and down the Kentucky River Valleys. The spectacle of a great ice-cascade, or of long ice-rapids, was then exhibited at Cincinnati. This cataract, or these rapids, must have been several hundred feet high. Down these cliffs or this slope the water dashed, melting its own channel,

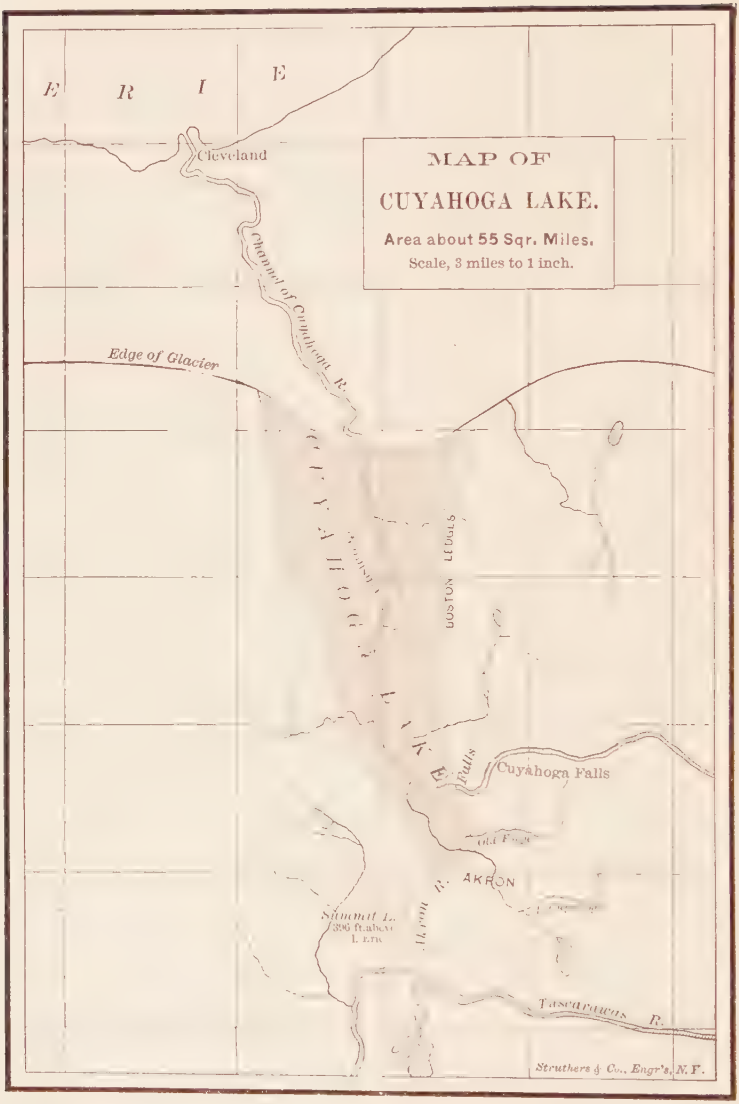

FIG. 112a.—Map illustrating a stage in the recession of the ice in Ohio. For a section of the deposit in the bed of this lakelet, see page 274. The gravel deposits formed at this stage along the outlet into the Tuscarawas River are very clearly marked (Claypole). ("Transactions of the Edinburgh Geological Society.")

and breaking up the foundations of its own dam. With the depression of the dam the level of the lake also fell. Possibly the change was gradual, and the dam and the lake went gently down together. Possibly, but not probably, this was the case. Far more likely is it that the melting was rapid, and that it sapped the strength of the dam faster than it lowered the water. This will be more probable if we consider the immense area to be drained. The catastrophe was then inevitable—the dam broke, and all the accumulated water of Lake Ohio was poured through the gap. Days or even weeks must have passed before it was all gone; but at last its bed was dry. The upper Ohio Valley was free from water, and Lake Ohio had passed away. . . .

But the whole tale is not yet told. Not once only did these tremendous floods occur. In the ensuing winter the dam was repaired by the advancing ice, relieved from the melting effects of the sun and of the floods. Year after year was this conflict repeated. How often we can not tell. But there came at last a summer when the Cincinnati dam was broken for the last time; when the winter with its snow and ice failed to renew it, when the channel remained permanently clear, and Lake Ohio had disappeared forever from the geography of North America. . . .

How many years or ages this conflict between the lake and the dam continued it is quite impossible to say, but the quantity of wreckage found in the valley of the lower Ohio, and even in that of the Mississippi, below their point of junction, is sufficient to convince us that it was no short time. "The age of Great Floods" formed a striking episode in the story of the "Retreat of the Ice." Long afterward must the valley have borne the marks of these disastrous torrents, far surpassing in intensity anything now known on the earth. The great flood of 1885, when the ice-laden water slowly rose seventy-three feet above low-water mark, will long be remembered by Cincinnati and her inhabitants. But that flood, terrible as it was, sinks into insignificance beside the furious torrent caused by the sudden, even though partial, breach of an ice-dam hundreds of feet in height, and the discharge of a body of water held behind it, and forming a lake of twenty thousand square miles in extent.

To the human dwellers in the Ohio Valley—for we have reason to believe that the valley was in that day tenanted by man—these floods must have proved disastrous in the extreme. It is scarcely likely that they were often forecast. The whole population of the bottom lands must have been repeatedly swept away; and it is far from being unlikely that in these and other similar catastrophes in different parts of the world,

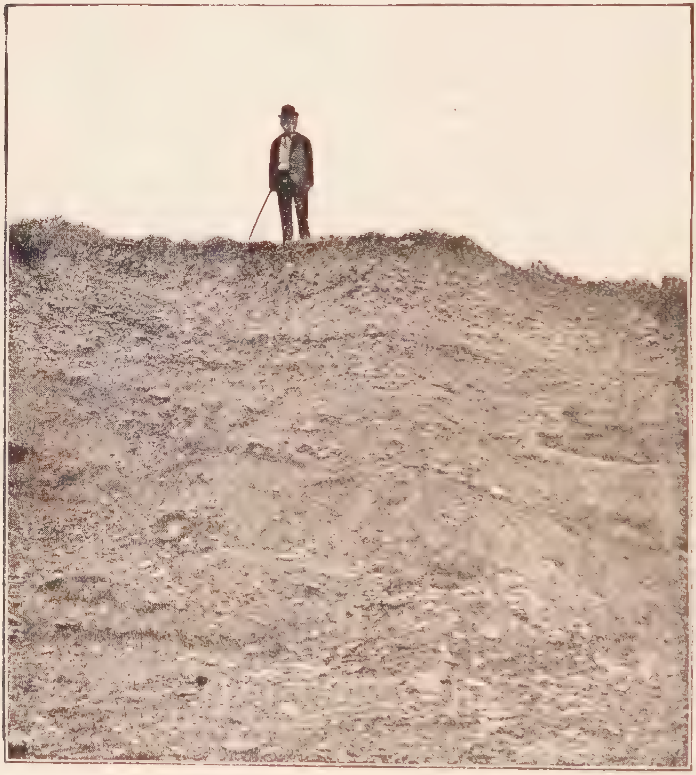

Fig. 113.—Section of the lake ridges near Sandusky, Ohio.

which characterized certain stages in the Glacial era, will be found the far-off basis on which rest those traditions of a flood that are found among almost all savage nations, especially in the north temperate zone.

Since the above account was written there has been a very animated discussion of the theory, the result of which has been to confirm the general view here maintained, while modifying some of the subsidiary points. Professor T. C. Chamberlin early expressed his disbelief in the dam, and after traversing the Monongahela Valley from Morgantown to Pittsburg expressed his belief that the clay deposits there, which Professor I. C. White had regarded as practically on a water level for a distance of more than 100 miles, were flood plain deposits of a flowing stream descending with the gradient of the valley. As Professor Chamberlin had taken pains to express this view in his introduction to my Bulletin published by the U. S. Geological Survey (No. 54), it became necessary for a committee of the American Association for the Advancement of Science to go over the ground with Professor White. The result was that everyone was convinced of the correctness of the facts as stated in my original publication.* It appeared that as Professor Chamberlin did not find Professor White at home, he failed to see the facts which Professor White had recorded. That an ice dam existed which ponded up the water in the Monongahela to a height of more than 1,000 feet above the sea is established beyond all controversy. But its immediate connection with the Cincinnati ice dam is now thrown into the background by the broader considerations already brought to light in discussing the formation of the present Ohio River.

The following facts detailed in a paper read, by Professor White, before the Geological Society of America,† at the Buffalo meeting in 1896 are as interesting as they are conclusive in establishing the existence of an ice-dam in the Upper Ohio Valley. At three different points the divide between the Upper Monongahela basin and the valley of the Ohio, is cut by

* "Bulletin of the Geological Society of America," vol xiv (1902), p. 4.

† Published in "Am Geol.," vol. xviii, Dec. 1896, "Origin of the High Terrace Deposits of the Monongahela River."

abandoned water weirs at an elevation of approximately 1,100 feet above tide. These are just such channels or "cols" as would be cut by the escaping water impounded by an ice-dam which obstructed the northerly drainage of the Monongahela. The terrace deposits of clay, quicksand, sand and gravel, bordering the river valley for more than 100 miles below Weston in West Virginia, range from 1,020 to 1,068 feet above tide, while that at Pittsburg is 990 feet above tide. The present river falls 290 feet between Weston and Pittsburg, while the terrace falls only forty feet in 200 miles at Pittsburg, and eight feet at Geneva, 117 miles below Weston. In tabular form the facts are as follows.

MILES		PRESENT RIVER A.T.	TOP OF DEPOSITS A.T.
0	Weston	990	1,030
40	Clarksburg	916	1,020
75	Fairmont	851	1,067
101	Morgantown	787	1,038
117	Geneva	772	1,022
206	Pittsburg	700	990

These terraces are specially prominent wherever a tributary comes into the main valley to form a delta at the level of the impounded water. Frequently the clay topping of the terrace is more than sixty feet thick, furnishing material for numerous pottery establishments.

The following plants were identified by Dr. F. H. Knowlton, as occurring in these clay deposits. 1. *Equisetum arvense L.*; 2. *Cyperus sp.*; 3. *Potamogeton robbinsii* Oakes; 4. *Liquidambar styracifolia L*; 5. *Platanus occidentalis* L (sycamore); 6. *Ulmus racemosa* Thomas (the white elm); 7. *Quercus falcata* Michigan; 8. *Betula nigra L.* (black birch); 9. *Fagus ferruginea* Ait (beech); 10. *Castanea pumila* Mill (chinquapin). All of these are living species, and most of them are still found in the vicinity. But special interest attaches to *Potamogeton robbinsii*, of which a great number of fragments of

stems and leaves were found. Its present distribution is from New Brunswick to New Jersey, north of Lake Superior and northward. The occurrence of this species in these beds is, as Professor White remarks, of special interest, since it practically demonstrates that there was during glacial times a movement of water from the edge of the ice near Beaver, Pennsylvania, southward along the Monongahela Valley, through the escape weirs just described, which brought with it this northern plant.

Since as already shown the preglacial drainage of both the upper and the middle portions of the Ohio basin was to the north, it follows that vast sheets of water were ponded up in front of the advancing ice-sheet from the moment that those northern outlets were closed. One of the most prominent of these would be that occupying the basin drained in preglacial times by the Monongahela and Lower Allegheny rivers, which originally flowed off through Beaver Creek and the Grand River valleys into Lake Erie a little east of Ashtabula. This temporary lake would have its level regulated by the height of the col already referred to at New Martinsville, a little below Wheeling, West Virginia. It was in this glacial lake that the deep still water clay deposits described along the Middle Monongahela accumulated. But after a comparatively short period the col at New Martinsville was worn down so that a permanent line of drainage was opened in that direction and Lake White, as we may be permitted to name it, no longer existed in the Monongahela Valley.

But as the ice-sheet continued to advance through central and southern Ohio the other lines of northerly drainage were obstructed and other temporary lakes formed which continued until the col, in the Muskingum above Zanesville, and that in the Ohio below the mouth of the Scioto were eroded sufficiently to permanently open present lines of drainage. Then, finally, when the ice reached the junction of Mill Creek Valley and the Great Miami at Hamilton, O., the whole drainage

which had been flowing in that direction was so obstructed that it was turned over the col which existed a little below Cincinnati, and the permanent channel was opened which is now followed by the Ohio River. During this period of erosion there was a temporary lake formed above Cincinnati, but of comparatively short duration, for the immense flow of water from the whole upper basin of the Ohio would work with great rapidity to cut down the col below the city.

After this there followed in immediate succession, the Cincinnati ice-dam proper, of which an account has been given. For a distance of fifty miles the ice advanced into Kentucky to heights of land fully 500 feet above the present level of the river, and must have obstructed the drainage up to that level. This was doubtless of comparatively short duration, but while it continued it would set the water in the whole valley above to that height, which would submerge Pittsburg to a depth of 300 feet, and reach far up both the Monongahela and the Allegheny rivers. The shortness of its duration, however, makes it difficult to distinguish its deposits from those which had been made during the continuance of the earlier ice-dams. While admitting therefore, that the "Cincinnati ice-dam" was at first somewhat overworked in accounting for the deposits in the Upper Ohio Valley, it is by no means ruled out of the problem. The Cincinnati ice-dam still remains a fact with which all students of the region are compelled to reckon.

As already intimated, however, the existence of the Cincinnati dam would necessitate an overflow either into the Kentucky River or around the margin of the ice, and such a channel, if it ever existed, should be easily discovered. But though I have diligently searched for it, it has so far eluded observation. This has inclined me to account for the Kentucky deposits as results of annual ice gorges, during the climax of the period, in the narrow channel below the city. But even so the phenomenon is none the less impressive, and would involve the flooding of the upper Ohio and its tributaries to the extent stated.

On coming to the region of the Great Lakes, the influence of ice-barriers is very conspicuous. South of Lake Erie there is an ascending series of what are called lake ridges. These are composed of sand and gravel, and consist largely of local material, and seem to maintain throughout their entire length a definite level with reference to the lake, though accurate measurements have not been made over the whole field. The approximation, however, is sufficiently perfect to permit us to speak of them as maintaining a uniform level. These ridges can be traced for scores of miles in a continuous line, and in the early settlement of the country were largely utilized for roads. In Lorain county, Ohio, an ascending series of four ridges can be distinguished at different levels above the lake.* The highest is from 200 to 220 feet above it; the next is approximately 150 to 160 feet; the next lower is from 100 to 118 feet; and the next lower less than 100 feet, while some appear on the islands near Sandusky which are not over 70 feet above the water-level. Eastward from Buffalo portions of this series have been traced, according to Gilbert, until they disappear against the highlands near Alden, on the Erie Railroad.

Lake Ontario is likewise bordered by similar ridges upon its southern and eastern sides, but the investigations in that region are not yet complete enough to be altogether satisfactory. From what has already been done it is evident that they do not maintain so nearly a uniform level as on the shores of Lake Erie. Mr. G. K. Gilbert, of the United States Geological Survey, informs me that, from the vicinity of Oneida Lake toward the northeast, the ridges rise rapidly with reference to the lake-level, and that to a less extent they rise in a westerly direction, showing that if they were water-deposits, there has been considerable oscillation of the land both northeast and southwest of an axis following the line of the Mohawk Valley.

That the ridges on Lake Erie mark temporary shore-lines

* "Geological Survey of Ohio," vol. ii, p. 207.

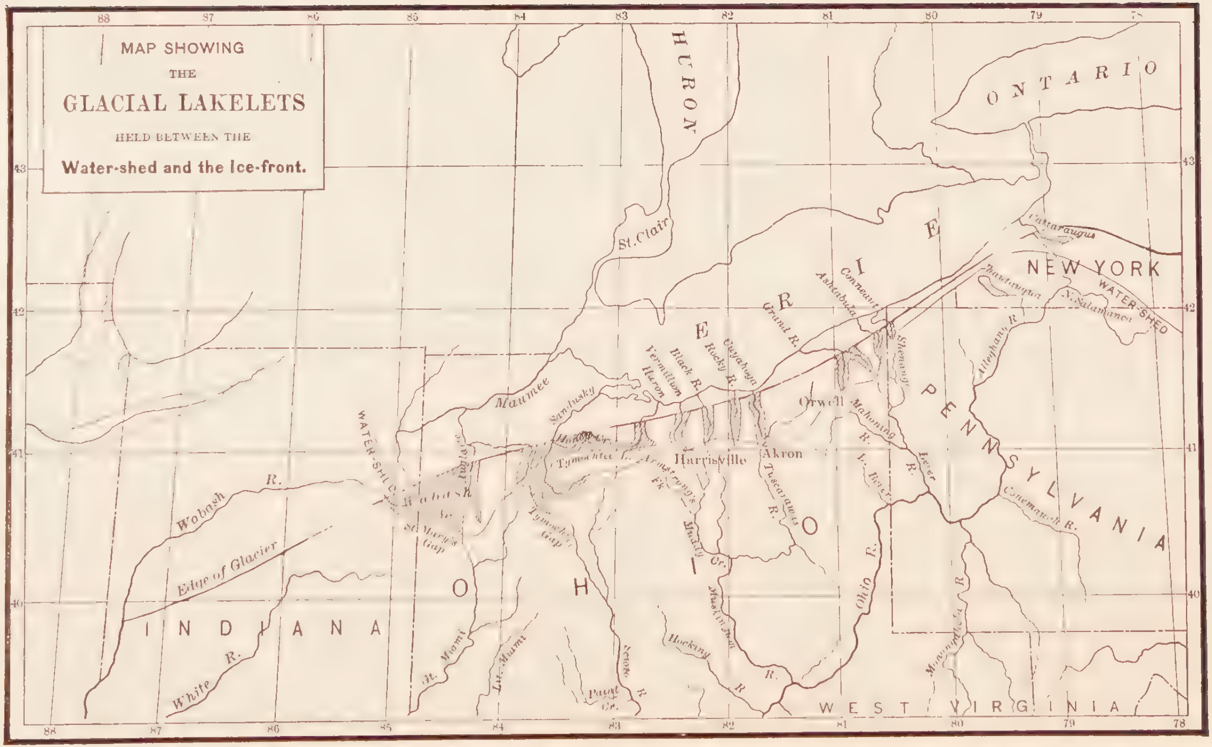

FIG. 114. Map showing formation of lakelets in northern Ohio, when the ice had withdrawn to the vicinity of the southern shore of Lake Erie (Claypole). ("Transactions of the Edinburgh Geological Society.")

of the lakes can not well be doubted, for they are not related to any great natural lines of drainage, but follow the windings of a definite level, receding from the lake wherever there is a transverse valley, and forming in some cases parallel embankments on either side of such valley, running inland as far as to the general level of the series, and then returning on itself upon the other side, to strike off again parallel with the shore at the same level. Their relation to the lake is also shown by the local character of the material. It is usually such as would wash up on the shore out of the rock in place. In the sandstone region the ridges are largely made up of sand, mingled with fragments from the general glacial deposit. Over the regions of outcropping shales the ridges are composed largely of the harder nodules which have successfully resisted the attrition of the waves. Other evidences that they are shore-deposits are their stratification, the relative steepness of their sides toward the lake, and the frequent occurrence of fragments of wood buried at greater or less depths on their outer margin.

It need not be said that there has been much speculation concerning the cause which maintained the waters of the lakes at the levels indicated by these ridges, and permitted them to fall from the level of one to that of another in successive stages, so suddenly as they seem to have done; for, from the absence of intermediate deposits, it is evident that the formation of one ridge had no sooner been completed, than the one at the next lower level began to form. In the earlier stages of glacial investigation, before the full power and flexibility of glacial ice were appreciated, and before the exact course of the southern boundary of the ice-sheet was known, the elevation of the water to produce these ridges was supposed to have resulted either from a general subsidence of the whole region to the ocean-level, or from the elevation of a rocky barrier across the outlet. Both these theories were attended with insuperable difficulties. In the first place, there is no such amount of collateral evidence to support the theory of general subsidence as there

should be if it really had occurred. The subsidence of the lake region to such an extent would have left countless other marks over a wide extent of country; but such marks are not to be found. Especially is there an absence of evidences of marine life. The cause was evidently more local than that of a general subsidence. The theory of the elevation of a rocky barrier would also seem to be ruled out of the field by the fact that no other direct evidence can be found of such recent local disturbances. Such facts as we have point to a *subsidence* at the east rather than to an elevation.

But a glance at the course of the terminal moraine, and at the relation of the outlets of these lakes to the great ice-movements of the Glacial period, brings to view a most likely cause for this former enlargement and increase in height of the surface of the lower lakes. It will be noticed that the glacial front near New York city was about one hundred miles farther south than it was in the vicinity of Buffalo. Hence the natural outlet to the Great Lakes through the Mohawk Valley would not have been opened until the ice-front over New England and eastern New York had retreated to the north well-nigh one hundred and fifty miles. A similar amount of retreat of the ice-front from its farthest extension in Cattaraugus county, in New York, would have carried it back thirty miles to the north of Lake Ontario, while a similar amount of retreat from eastern Ohio would have left nearly all the present bed of Lake Erie free from glacial ice. With little doubt, therefore, we have, in the lake ridges of Upper Canada, New York, and Ohio, evidence of the existence of an ice-barrier which continued to fill the valley of the Mohawk, and choke up the outlet through the St. Lawrence, long after the glacial front farther to the west had withdrawn itself to Canada soil. A study of these ridges may yet shed important light upon the length of time during which this ice-barrier continued across the valley of the Mohawk.

FIG. 115—Lake Whittlesey, with correlative ice border. (Map by Leverett.)

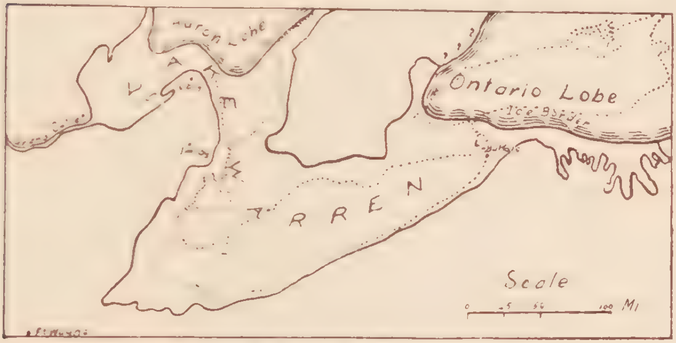

FIG. 116—Lake Warren, with probable correlative ice border. (Map by Leverett.)

FIG. 117—Nipissing Great Lakes and Champlain Sea. Numerous isobases give altitude above sea level of the highest exposed shore. Isobases of Michigan and Huron basins by Taylor and Goldthwaite.

FIG. 118.—Map showing the condition of things when the ice-front had withdrawn about one hundred and twenty miles, and while it still filled the valley of the Mohawk. The outlet was then through the Wabash. Niagara was not yet born (Claypole). ("Transactions Edinburgh Geological Society.")


MAP OF THE
GLACIAL LAKE AGASSIZ,
showing its relation to
HUDSON BAY AND THE GREAT LAKES.
BY WARREN UPHAM, D.Sc.,
Assistant on the Geological Surveys of Minnesota,
the United States, and Canada
Boundaries of Lake Agassiz and Associated Glacial Lakes
Terminal Moraines
Glacial Striae
HUDSON BAY
JAMES BAY
UNGAVA
P.Q.
KEEWATIN
SASKATCHEWAN
ALBERTA
MANITOBA
ONTARIO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
MICHIGAN
LAKE AGASSIZ
LAKE WINNIPEG
L. WINNIPEGOSIS
L. MANITOBA
LAKE SOURIS
LAKE SASKATCHEWAN
LAKE DAKOTA
LAKE MINNESOTA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
GEORGIAN BAY
REINDEER LAKE
Methy Portage
Athabasca River
English or Churchill River
Nelson River
Hayes R.
Severn R.
Equan R.
Attawapishkat River
Albany River
Kenogami R.
Moose R.
Abittibi R.
Big R.
E. Main R.
North Saskatchewan River
South Saskatchewan River
Elbow
Qu'Appelle R.
Assiniboine River
Souris or Mouse R.
Red River
James R.
Missouri River
Milk R.
Mississippi River
Minnesota Glacial R. Warren
Approximate Boundary formed by the receding Ice-Sheet
International Boundary
Margin of the North Glacial Drift
Driftless Area
L. of the Woods
Lac Seul
L. St Joseph
Lake Nipigon
Beltrami Island
Mesabi Range
Duck Mountain
Beaver Hills
Porcupine Hills
Turtle Mountain
Wood Mountain
Cypress Hills
Hand Hills
Coteau
Coteau des Prairies
Leaf Hills
114
112
110
108
106
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44

THE GLACIAL LAKE AGASSIZ

By Warren Upham, D.Sc.,

St. Paul, Minn.

As soon as the departing ice-sheet, which had enveloped the northern United States and British America during the glacial period, in its final melting off the land from south to north, receded beyond the water-shed dividing the basin of the Minnesota River from that of the Red River of the North, a lake, fed by the glacial melting, stood at the foot of the ice-fields, and extended northward as they withdrew along the valleys of the Red River to Lake Winnipeg, filling this valley and its branches to the heights of the lowest points over which an outlet could be found. Until the ice-barrier was melted away on the area now crossed by the Nelson River, thereby gradually draining this glacial lake, its outlet was along the present course of the Minnesota River. At first its overflow was upon the nearly level undulating surface of the drift, 1,050 to 1,125 feet above the sea, at the west side of Traverse and Big Stone counties, Minnesota; but in process of time this cut a channel there, called Brown's Valley, 100 to 150 feet deep and about a mile wide, the highest point of which, on the present water divide between the Mississippi and Nelson river basins, is 975 feet above the sea-level. From this outlet the Red River valley plain extends 315 miles north to Lake Winnipeg, which is 710 feet above the sea. Along this entire distance there is a very uniform continuous descent of a little less than one foot per mile.

The farmers and other residents of this fertile plain are well aware that they live on the area once occupied by a great lake; for its beaches, having the form of smoothly rounded ridges of gravel and sand, a few feet high, with a width of several rods, are observable extending almost horizontally long distances upon each of the slopes which rise east and west of the valley plain. Hundreds of farmers have located their

buildings on these beach ridges as the most dry and sightly spots on their lands, affording opportunity for perfectly drained cellars even in the wettest seasons, and also yielding to wells, dug through this sand and gravel, better water than is usually obtainable in wells on the adjacent clay areas. While each of these farmers, in fact every one living in the Red River Valley, recognizes that it is an old lake bed, few probably know that it has become for this reason a district of special interest to geologists, who have traced and mapped its upper shore along a distance of about 800 miles.

Numerous explorers of this region, from Long and Keating in 1823, to Gen. G. K. Warren in 1868 and Prof. N. H. Winchell in 1872, recognized the lacustrine features of the valley; and the last named geologist first gave what has been generally accepted as the true explanation of the existence of the lake, namely, that it was produced in the closing stage of the glacial period by the dam of the continental ice-sheet at the time of its melting away. As the border of the ice-sheet retreated northward along the Red River Valley, drainage from that area could not flow as now freely to the north through Lake Winnipeg and into the ocean at Hudson Bay, but was turned by the ice-barrier to flow south across the lowest place on the water-shed, dividing this basin from that of the Mississippi. This lowest point is found, as before noted, at Brown's Valley on the western boundary of Minnesota, where an ancient water-course, about 125 feet deep and one mile to one and a half miles wide, extends from Lake Traverse, at the head of the Bois des Sioux, a tributary of the Red River, to Big Stone Lake, through which the head stream of the Minnesota River passes in its course to the Mississippi and the Gulf of Mexico.

Detailed exploration of the shore lines and area of this lake was begun by the present writer for the Minnesota Geological Survey in the years 1879 to 1881, under the direction of Professor N. H. Winchell, the State geologist. In

subsequent years I was employed also in tracing the old lake shores through North Dakota for the United States Geological Survey, and in Southern Manitoba, to the distance of 100 miles north from the international boundary to Riding Mountain, for the Geological Survey of Canada. For the last named survey, Mr. J. B. Tyrrell extended the exploration of the lake shore lines more or less completely for 200 miles farther north along the Riding and Duck mountains and the Porcupine and Pasquia hills, west of Lakes Manitoba and Winnipegosis, to the Saskatchewan River.

This glacial lake was named by me in the eighth annual report of the Minnesota Geological Survey, for the year 1879, in honor of Louis Agassiz, the first prominent advocate of the theory of the formation of the drift by land ice; and the outflowing river, whose channel is now occupied by Lakes Traverse and Big Stone and Brown's Valley, was named also by me, in a paper read before the American Association for the Advancement of Science at its Minneapolis meeting in 1883, the River Warren, in commemoration of General Warren's admirable work in the United States Engineering Corps, in publishing maps and reports of the Minnesota and Mississippi River surveys.

Descriptions of Lake Agassiz and the River Warren are somewhat fully given in the eighth and eleventh annual reports of the Minnesota Geological Survey, and in the first, second, and fourth volumes of its final report. Three other special reports of my explorations of Lake Agassiz were published; the first in 1887, as Bulletin No. 39, of 84 pages, with a map, by the Geological Survey of the United States; the second in 1890, by that of Canada, in its Annual Report, New Series, vol. iv, for 1888-89, forming Part E, 156 pages, with maps and sections; and last, this subject was most fully issued by the U. S. Geological Survey, as its Monograph XXV, 1895, a quarto volume of 658 pages and 38 plates (maps, views, and sections).

Several successive levels of the ancient lake are recorded by distinct and approximately parallel beaches, due to the gradual lowering of the outlet by the erosion of the channel at Brown's Valley, and these are named principally from stations on the Breckenridge and Wahpeton line of the Great Northern Railway, in their descending order, the Herman, Norcross, Tintah, Campbell, and McCauleyville beaches, because they pass through or near these stations and towns.

The highest or Herman beach is traced in Minnesota from the northern end of Lake Traverse eastward to Herman, and thence northward, passing a few miles east of Barnesville, through Muskoda, on the Northern Pacific Railway, and around the west and north sides of Maple Lake, which lies about twenty miles east—southeast of Crookston, beyond which it goes eastward to the south side of Red and Rainy lakes. In North Dakota the Herman shore lies about four miles west of Wheatland, on the Northern Pacific Railway, and the same distance west of Larimore, on the Pacific line of the Great Northern Railway. On the international boundary, in passing from North Dakota into Manitoba, this shore coincides with the escarpment or front of the Pembina Mountain plateau, and beyond passes northwest to Brandon on the Assiniboine River, and thence northeast to the Riding mountain.

Leveling along this highest beach shows that Lake Agassiz, in its earliest and highest stage, was nearly 200 feet deep above Moorhead and Fargo; a little more than 300 feet deep above Grand Forks and Crookston; about 450 feet above Pembina, St. Vincent, and Emerson; more than 500 feet above the city of Winnipeg; and about 500 and 600 feet, respectively, above Lakes Manitoba and Winnipeg. The length of Lake Agassiz is estimated to have been nearly 700 miles, and its area not less than 110,000 square miles, exceeding the combined areas of the five great lakes tributary to the St. Lawrence.

When the ice-barrier was so far melted back as to give outlets northeastward lower than the River Warren, other beaches marking these lower levels of the glacial lake were formed; and finally, by the full departure of the ice, Lake Agassiz was drained away to its present representative, Lake Winnipeg.

The rate of the northward ascent of the originally level highest beach, within the area of my leveling, varied from about six inches per mile near its southern end to about one foot per mile along the greater part of its extent to southern Manitoba. On the east side of the Red River Valley the old shores are higher than on its west side, the rate of ascent from west to east being about half as much as from south to north. The direction of maximum ascent of the planes of the former lake levels is therefore toward the north-northeast. Farther north several beaches of the series mapped by Tyrrell along the bases of the Riding and Duck mountains have a northward rise of two or three feet per mile. The changes of level were in progress and were nearly completed during the existence of Lake Agassiz, as is shown by the gradual diminution in the northward ascent of the successive lower beaches, until the latest and lowest differs only slightly from perfect horizontality.

Gravitation of Lake Agassiz toward the ice-sheet accounts for a small part of the present inclination of the beaches. Changes in the temperature of the earth's crust due to the glacial period and its termination produced a still smaller effect, but this tended to give the opposite slope, or a descent toward the north. Upward movement of this great land area, resulting from its being unburdened by the departure of the ice-sheet, was the chief element in the causes of the differential changes in the height of this basin. Flow of the plastic inner part of the earth's mass, restoring its equilibrium or isostasy, uplifted first the southern half of the area of Lake Agassiz, from Lake Traverse to Gladstone in Manitoba; next it raised

the northern half of the lake area, while the region at the south was almost at rest; and finally, during the recent epoch, after the whole basin of Lake Agassiz was passed by this wave like permanent uplift, it has been elevating the basin of Hudson Bay, where the movement appears to be still in progress. Pleistocene oscillations of the land in many other parts of the world have been independent of glaciation, or these have been combined with movements due to the accumulation of ice-sheets and to their removal; but the uplifting of the basins of Lake Agassiz and Hudson Bay is apparently attributable wholly to the departure of the ice-sheet.

The entire duration of Lake Agassiz, estimated from the amount of its wave action in erosion and in the accumulation of beach gravel and sand, appears to have been only about 1,000 years; and the time of its existence and of the end of the ice age is thought, from the rate of recession of the Falls of St. Anthony, cutting the post-glacial gorge of the Mississippi River from Fort Snelling to Minneapolis, to have been somewhere between 6,000 and 10,000 years ago.

CHAPTER XVI.

THE LOESS.

THE deposit called *loess* received its name in Germany, where it was first described. But its most remarkable developments are in China and in America. The formation is one of great interest in every respect. It furnishes the most fruitful soil in the world, and is extensively used for the excavation of houses in China and in some parts of America. At the same time it presents the scientific observer with a most attractive but puzzling problem. Professor Pumpelly, who has seen it in all parts of the world, gives the following lucid description of the deposit :

This remarkable formation covers several hundred thousand square miles in northern China, and larger areas in the rest of Asia. It forms the soil also over an immense area in the western United States. Its thickness varies in China up to two thousand feet, and to one hundred and fifty and two hundred feet in Europe and America.

Loess is a calcareous loam. It is easily crushed in the hand to an almost impalpable powder, and yet its consistency is such that it will support itself for many years in vertical cliffs two hundred feet high. A close examination shows that it is filled with tubular pores branching downward like rootlets, and that these tubes are lined with carbonate of lime. It is to these that it owes its consistency and its vertical internal structure. It is wholly unstratified, and often where erosion has cut into it, whether one foot or one hundred yards, the walls are absolutely vertical. Its vertical internal structure causes it to break off in any vertical plane, but in no other. Hence, when

a cliff is undermined, the loess breaks off in immense vertical plates leaving again a perpendicular wall.

It is divided into beds varying in thickness from one foot to two or three hundred, which thin out to nothing at the borders and are separated by parting planes. These planes are marked by angular *débris* near the mountains, and by elongated upright calcareous concretions elsewhere.

This remarkable combination of softness with great strength and stability of exposed surfaces is of inestimable value in a woodless country. In Asia, thousands of villages are excavated in a most systematic manner at the base of cliffs of loess. Doors and windows pierced through the natural front give light and air to suites of rooms which are separated by natural walls, and plastered with a cement made from the loess concretions. These are the comfortable dwellings of many millions of Chinese farmers, and correspond to the ruder dug-outs of Nebraska.

To the same qualities is due the fact that the loess districts of China are exceedingly fertile plains, in each of which a rapidly progressing erosion has excavated the most labyrinthine valley systems, in which all the members, down to the smallest tributaries, are sunk with vertical walls to depths of from one hundred to several hundred feet. Even the wagon-roads become in time depressed to a depth of fifty feet and more by the removal of the dust by wind.

There is one more peculiarity of the loess: it not only is wholly unstratified, but it contains the remains of only land-animals and especially of land-snails. Alexander Braun examined 211,968 specimens of shells from the loess of the Rhine between Basle and Bonn, and found that all were land-snails except only thirty-three individuals, consisting of *Limnæa*, *Planorbis*, and *Vitrina*, which came from three isolated points in the valley of the Rhine and Neckar.

Baron Richthofen, after prolonged study of the loess of China, propounded the theory that it was a wind-deposit, consisting of material which had resulted from the slow disintegration of the rocks in the arid regions of central Asia, from which the westerly winds have been continually blow-

ing for an untold period. As applicable to China, Richthofen's theory is perhaps adequate. Mr. Pumpelly is also inclined to accept the theory as applicable to America, remarking that—

No one can realize the capacity of wind as a transporter of fine material who has not lived through at least one great storm on a desert. In such a simoon the atmosphere is filled with a driving mass of dust and sand which hides the country under a mantle of impenetrable darkness, and penetrates every fabric; it often destroys life by suffocation, and leaves in places a deposit several feet deep.

The prevailing westerly wind, carrying sand, carves and polishes the rocky crest of the Sierra Nevada, and, as Mr. King tells me, has formed long wind-stream deltas—if I may coin the term—in the form of lofty sand ranges stretching from each pass eastward, far out on the desert.

The often cited instances of far-driven volcanic ashes show the ability of the wind to carry comparatively coarse dust through distances of several hundred miles, but it does not seem improbable that the finer particles may remain suspended while the wind makes a complete circuit of the globe. I witnessed on March 31st and April 1st, in 1863, a dust-fog at Nagasaki which lasted two days, and left only a just perceptible film of dust, observable only on the white, newly painted deck of a yacht. A similar fall occurred simultaneously at Shanghai, and both were contemporaneous with a terrific dust-storm which during two days shrouded the country about Tientsin in deep darkness.

I am indebted again to Mr. Clarence King for the statement that dust-fogs occur on the coast of California with the prevailing west wind; and this may be, as he suggests, the finest residuum of the loess-dust of an Asiatic dust-storm.*

Concerning the power of wind to transport dust, many other striking illustrations have been noted. Showers of reddish dust occasionally fall upon ships far out at sea. Darwin describes one such storm encountered by him near the Cape

* "American Journal of Science," vol. cxvii, 1879, pp. 133, 134, 139.

Verds, which was estimated to be sixteen hundred miles broad. A similar shower which passed over the southern part of France in 1846 is estimated by Ehrenberg to have deposited nearly a million pounds of dust. On examination he found that about one eighth of it consisted of microscopic organisms, many of which belonged in South America, thus showing that the wind had blown the dust across the Atlantic. In 1835 volcanic dust was blown from Guatemala to Jamaica, a distance of eight hundred miles.

The main difficulty of applying the wind theory to account for the loess of the Mississippi Valley and of Europe lies in its definite relation to water-levels. For example, in the Rhine Valley the loess rests in places upon elevations of eight hundred feet above the river, but does not occur at higher levels. This would clearly indicate that it is a water-deposit. The problem has been to conceive how the water could be maintained at that level in the valley of the Rhine; and the theory has been put forth, and ably defended by Geikie and others, that the Rhine and other rivers emptying into the North Sea were obstructed at their mouths by the Scandinavian glaciers, and so the water was ponded back toward the Alps to the level at which the loess ceases.

The absence of fossils of aqueous origin in the loess may be accounted for in two ways: 1. If the deposit took place, as was supposed, in temporary glacial lakes, there may have been no species existing in them to have left their remains. This would be likely to be the case for three reasons: (1) the lakes were of only temporary continuance; (2) the temperature of the water must have been abnormally low; and (3) the superabundance of silt might interfere with animal life. 2. Professor Hilgard has suggested that the porosity of the loess, which favors the continual presence and percolation of water charged with acids throughout its mass, renders it almost certain that any inclosed fossils would have been rapidly dissolved. As to why this oxidizing and dissolving process should have selected fossils of aqueous origin, and made an exception in favor of those of terrestrial animals,

Professor Hilgard explains that the terrestrial fossils are, as a matter of fact, found near the marginal portion of the loess, where the destructive processes are least. Whether, also, there may not be a difference between the destructibility of land- and fresh-water shells is also a question. The occurrence of nodules of lime throughout the mass points to such a work of solution and redistribution by water. In regard to the frequent occurrence of the bones of the larger land-animals, Professor Hilgard remarks: "That the phosphatic bones should not have dissolved as easily as the mere carbonate shells is readily intelligible; and as regards their mode of occurrence in the loess of the lower Mississippi they are

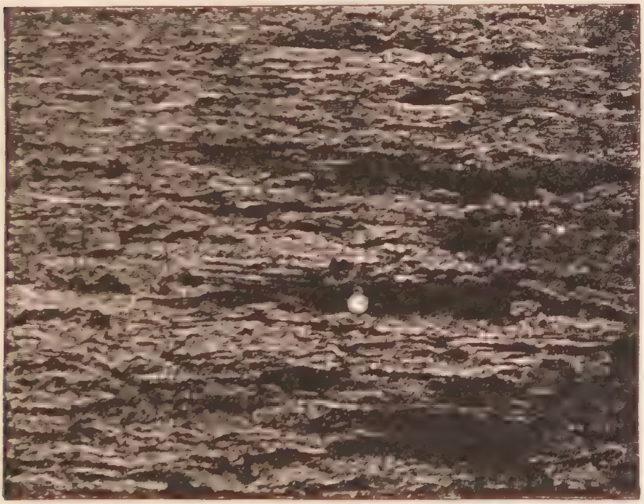

Fig. 119.—Stratification of the loess in a railway cut at Plattsmouth, Nebraska, at a depth of eighty-four feet from the surface. (From photograph furnished by Dr. A. L Child, of Kansas City, Mo.) (Chamberlin.) (United States Geological Survey.)

always very much scattered, many bones belonging to the same individual being rarely found together, but seeming to have drifted widely apart. It is not easy to see how the cumbrous bones of the mammoth could have been widely separated in a subaërial deposit." *

* "American Journal of Science," vol. cxviii, 1879, p. 110.

It is to President Chamberlin, again,* that we are indebted for the most careful study of this problem in the Mississippi Valley. According to him, the loess is limited predominantly to the river valleys, and the belt is ordinarily not over forty miles in width. As a rule, also, it is thicker and slightly coarser in character near the banks of the great rivers, and there shows some signs of stratification.

A comparison of loess with sand and clay reveals some interesting facts. The loess is intermediate in size and fineness. When the particles are suspended in water, the loess settles much more rapidly than clay—as much of the loess settling in four hours as of the clay in thirty-six hours. Out of 150,000 particles of loess examined under the microscope, 146,000, or about ninety-seven per cent, were less than ·005 of a millimetre in diameter. A grain of sand one millimetre in diameter is considered fine. But this would make 200,000 particles of loess of the size mentioned, and 100,000 particles of the fineness of a large part of true clay. The size of the largest particles of loess noted by President Chamberlin was about one tenth of a millimetre in size, and consisted of scales of mica. The loess of Vicksburg is a little finer than that of Kansas City, and both a little finer than that from the Rhine. The particles of loess were found to be angular and irregular. "Sharp corners and rough surfaces are the rule, and any approach to regularity or smoothness is the exception." In the vicinity of the great rivers the grains are coarser than at points removed from them. In chemical composition the difference between loess and true residual clays is not very striking; but, as compared with glacial clays, occurring in the till, there is a marked difference in several respects. The glacial clays have far less amount of silica and alumina, and a far larger amount of calcic and magnesian oxides and of carbonic dioxides. The glacial clays are evidently the result largely of mechanical abrasion; but the loess would seem to consist in larger proportion of material resulting from chemical dis-

* "Driftless Area of the Upper Mississippi Valley," pp. 278–307.

integration. But the amount of kaolinized products is nearly four times as great in the residuary clays as in glacial clays or loess.

The altitude of the loess deposits in the Northwest is by no means uniform, and its variations present great theoretic difficulties. In the lower part of the Mississippi Valley it is limited to a height of about two hundred and fifty feet. In the upper Mississippi Valley, however, it rises to a height of seven hundred feet above the bed of the river. To account for this, the first impulse would be to suppose a general depression of the northern region. But this theory is excluded by various irregularities in this region itself. For example, the loess rises much higher upon the west side of the upper Mississippi than upon the east side, especially in the vicinity of the driftless area of Wisconsin.

To explain this it is necessary to resort to a rather complex theory. In part, perhaps, the peculiar distribution of loess is attributable to a period of general northerly depression during the Glacial epoch. This apparent depression, however, was probably not caused wholly by an oscillation of the crust of the earth itself, since it is shown that it may be due in some degree to the attraction of the ice which had accumulated to the north. Mr. R. S. Woodward, of the United States Geological Survey, has worked out the problem of attraction and its influence in producing a higher level of water at the north, on the supposition that the ice-sheet was ten thousand feet thick, and covered an area to the north 2,600 miles in diameter, and finds that the possible influence of such attraction might change the water-level at the ice-margin thirty-eight degrees from its center as much as 573 feet. But the elevation of the loess attains a height in Iowa and Wisconsin of 1,285 feet. This theory of change of the water-level by glacial attraction, therefore, though not adequate, very evidently comes in for a part of the credit of producing the puzzling facts relating to the deposition of loess.*

* "Driftless Area of the Upper Mississippi Valley," pp. 291–301.

A noticeable phenomenon west of the driftless area in Wisconsin and Iowa is that the loess is thickest near the eastern margin of the ice-lobe which passed southward through central Iowa. The distance from the driftless area to the Missouri River, or the width of this lobe in the latitude of Milwaukee, is not far from three hundred and forty miles. It is urged that the presence of an ice-lobe over that region may have had influence in elevating the loess deposits. Since attraction varies inversely as the square of the distance, such a mass of ice near at hand would slightly raise the water along its margin. The objection to this is that the wider ice-lobe to the east did not produce corresponding influence.

Among the more fruitful supplementary hypotheses brought in to aid in the solution of this part of the problem is to be mentioned that of glacial dams similar to those already alluded to in Europe. In this country the principal field in which they may have existed is where it is most needed, namely, west of the Mississippi. An examination of our map will at once suggest that it is possible for much of the loess in northeastern Kansas and eastern Nebraska to have accumulated in temporary lakes formed by glacial dams across the mouth of the Kansas and Platte Rivers, or even of the Missouri itself. How far this cause may have operated remains yet to be determined.

So complicated are the facts pertaining to the loess as they now appear, that it is not likely that, for some time to come, investigators will arrive at a perfect agreement concerning its manner of deposition. Those, however, who have most attentively studied glacial phenomena may be pardoned if they work the glacial hypothesis for all that it is worth. The existence of the vast body of ice which covered the glaciated area introduces a very complicated and efficient cause which it is exceedingly difficult to eliminate from the problem; and it is as allowable for the glacialist to take refuge in supposed ice-dams, where their existence is possible and can not be disproved, as for the ordinary geologist to suppose vast orographic changes. The study of the loess has

not come so much within my own field of observation as other glacial deposits have done. Still, in southern Indiana and Illinois, and in western Iowa and eastern Nebraska, I have been able to study many typical regions of this deposit; and the more attention I have given to the subject, the more I have been led to magnify the agencies of the Ice period in producing the results both positive and negative. I have come, therefore, to set an increasingly high estimate upon the suggestions of Mr. Upham, made after he had concluded his survey of the terminal moraine in Minnesota, Iowa, and eastern Dakota:

When the ice-sheet extended to the Coteau du Missouri, the Coteau des Prairies, and the Kettle-Moraine, the floods formed by its summer meltings were carried southward by the present avenues of drainage, the streams which occupied the areas between its great lobes in order from west to east being the Big Sioux, Mississippi, and Wisconsin Rivers. The vast glaciers which were gathered up on the Rocky Mountains, and the ice-fields which sloped downward to their termination at the coteaus and the moraine north and east in Minnesota and Wisconsin, supplied every summer immense floods laded with silt, sand, and gravel, that had been contained in the melting ice. Very extensive deposits of modified drift were thus spread along the course of the swollen Missouri and Mississippi. The Orange sand and gravel, described by Professor E. W. Hilgard and others in the lower Mississippi Valley, appear to have been deposited in this way, but during the earlier Glacial epoch, when an ice-sheet reached in Dakota beyond the Missouri River to a termination forty miles west and twenty miles southwest of Bismarck, into northeastern Kansas, half-way across the State of Missouri, and nearly to the Ohio River.

In the closing stages of this epoch, and during the time succeeding, till the date of the terminal moraine of the coteaus, and especially at the final retreat of the ice-sheet of this later epoch, the deposition of the overlying, finely pulverized, arenaceous and calcareous silt, called the Bluff formation, or loess, took place. This covers considerable areas along the Mis-

sissippi from southeastern Minnesota to its mouth; but its greatest thickness and extent are found in the basin of the Missouri River from southern Dakota to its junction with the Mississippi, and upon the region crossed by the Platte or Nebraska River, its longest tributary from the west, which takes its head-waters from a large district of the Rocky Mountains. The continuity of this formation from the borders of the ice-sheet and the glaciers of the Rocky Mountains to the shores of the Gulf of Mexico, the absence from it of marine shells, and the presence of land- and fresh-water shells, indicate that its deposition was by slowly descending floods, uplifted upon the surface of this sediment which was being accumulated during every summer through a long epoch, in the same manner that alluvium is now spread upon the bottom-lands of our rivers at their times of overflow. The occurrence of the loess in Guthrie, Carroll, Sac, and Buena Vista counties * in Iowa, covering the region next west of the terminal moraine, with its surface fifty feet above these drift-hills and one hundred above the undulating area of till adjoining their east side, proves that during the time of deposition of this part of the loess the ice-sheet extended to this limit, and was a barrier preventing the waters by which this sediment was brought from flowing over the lower area of till that reaches thence east to the Des Moines River. When the ice-sheet retreated beyond the watershed of the Missouri basin, the principal source of these floods and their sediment was removed, and the subsequent work of the rivers which cross the area of the loess has been to excavate their present valleys or channels, bounded by bluffs of this formation. †

A supplementary hypothesis to account for the subsidence assumed by some is, that a bodily depression of the crust of the earth was produced by the weight of the glacier. If one is inclined at first thought to reject this cause as inoperative because of its relative insignificance, he should reflect that

* "The Ninth Annual Report of the Geological and Natural History Survey of Minnesota," p. 307 *et seq.*

† Ibid., pp. 337, 338.

the forces maintaining the present contour of the earth's surface may be very evenly balanced, so that a slight addition at one point, and subtraction from another, might be the decisive influence in turning the scale. It is now pretty generally believed that the long-continued and steady periods of subsidence involved in the formation of extensive sedimentary rocks was due to the constant accumulation of the silt, out of which the rocks are made. This silt was relieving the continents of its weight, and adding to the weight along the whole line of deposition. During the Glacial period the transference of water from the ocean to accumulate as ice upon land removed an immense pressure from the ocean-beds, and added an equal amount of weight to the glaciated area. How much influence this may have had in depressing temporarily this area and its margin, we are unable to tell. But it is one of those unknown causes in the field which may be supposed to have accomplished something.

Professor Alexander Winchell has, in a recent interesting paper, suggested a correlation between this pressure of the ice over the glaciated region and the enormous outflows of lava along the Rocky Mountains and the Cascade Range on the Pacific slope.* The lava-beds of that region are enormous in extent and are certainly of very recent date, and seem to have poured out from long fissures instead of craters. Underneath these beds there are, in California and Oregon, glacial deposits; and it is in these lava-covered glacial deposits of southern California that human remains are supposed by Whitney to have been found. Professor Winchell's theory connecting those lava outflows with the depression produced by the ice of the Glacial period in the east would relieve the subject of considerable embarrassment arising from the chronological difficulties that have been suggested. To the superficial objection that pressure over the Mississippi Valley would not produce volcanic eruptions at so great a distance

* "Some Effect of Pressure of a Continental Glacier," in "The American Geologist," March, 1888, pp. 139–143.

as the Pacific coast, it is readily answered: "The terrestrial globe in some of its behavior may be compared to an India-rubber ball filled with water. If indented by pressure in one place, there must be a protuberance equal in volume in another place. In a ball of uniform composition, the protuberance would be spread over the entire surface beyond the region indented, and the effect in one particular spot might be insignificant. Should a small area of the caoutchouc be thinner than the rest, that part would be protruded to a greater extent than other parts of the surface. Should there be small holes or fissures through it, the water would escape and flow over the surface—that is, the protuberance resulting from local pressure would be chiefly on the outside of the shell. As we ordinarily conceive it, the water would be squeezed out like the juice of a squeezed orange."*

Another supplementary theory which has been invoked to account for the loess, is, that it has, in certain sections at least, been brought to the surface by the agency of earthworms and other animals which burrow in the ground. The remarkable facts adduced by Mr. Darwin concerning the activity of these humble agents give respectability to the theory; and, indeed, the power of these agencies can be seen by any observer who will take the pains to notice the countless marks of angle-worms which frequently appear upon the surface of the soil after a rain. Mr. Darwin estimated that the amount of soil brought to the surface by worms was in one case at the rate of nearly two tenths of an inch a year. It is estimated, also, by competent authority, that the number of worms to an acre is as great as fifty-four thousand and that they would weigh three hundred and fifty-six pounds. Trustworthy estimates also show that these creatures sometimes raise annually to the surface fourteen tons, and again eighteen tons, to the acre.† From this it is easily seen that the predominance of fine earth upon the surface is due to the

* "Some Effect of Pressure of a Continental Glacier," p. 139.

† See Darwin, on "Vegetable Mould and Earth-Worms," chaps. iii and iv.

work of such animals as worms, crayfish, and ants. But these creatures are limited in the depth to which they can penetrate the soil and convey it to the surface. Still, it is not improbable that in many places where the loess-like deposits are shallow it may be the result of these agencies.

The twenty years which have elapsed since this chapter was written have been marked by continuous discussion of this puzzling problem of the loess. But its solution seems still about as far distant as ever. The Richthofen theory which accounts for its accumulation and distribution by wind has now more supporters than ever. But there is still a large residuum of facts that resist explanation on that theory alone. The loess of China has doubtless accumulated in the mountainous region bordering on Mongolia through the agency of wind, which has brought it in from the desert wastes which stretch westward to the "roof of the World" in Central Asia. But even so it is a question whether the material was not ultimately of glacial origin.

In the revised edition of Geikie's "Great Ice Age" it is represented that an ice field covered eastern Mongolia which would presumably furnish the required glacial grist. But after the demonstration that eastern Mongolia never supported ice fields, the glacialists were compelled to resort to the theory that the wind had brought the material across the desert of Gobi, all the way from the base of the mountains, which on three sides surround the Tarim Valley. Here during the glacial period there was a great extension of glaciers in the Pamir and in the Tian Shan and the Himalaya mountains. It is to the floods pouring from the fronts of these glaciers that some would look for the supply of loess which the winds have brought into the mountain border of eastern Mongolia. It is difficult to say that this cause is not adequate to the effect, for the prevailing winds are westerly over this whole region and loess when once started could easily be driven at successive stages for any required distance. I can add my personal

testimony to the extent and effects of the dust storms in eastern Mongolia, where for a day at a time the dust raised by the wind was so dense that objects could not be distinguished half way across the road. And I have described immense drifts of loess near the summits of the mountains in that region five thousand feet above the sea, where it was impossible to invoke the agency of water to account for the accumulation.

But the investigations of Huntington and others seem to show that loess is not exclusively of glacial origin, but may be the finer product of subaërial disintegration, such as is going on all the while in desert regions such as exist in Central Asia and in the Rocky Mountain plateau. Still, whatever be the ultimate origin of the material, and however much influence we may attribute to the wind in transporting it from its original place of formation, water must be allowed a large share in its final distribution, and its accumulation belongs to a definite period corresponding to that of the glacial period. It is perfectly evident to one who traverses the mountainous region of eastern Mongolia that loess is not now accumulating there through the agency of wind as fast as it is being removed by water, and carried down to the lower levels of the Yangtsi and Hoang rivers, and by them distributed along the shores of the Chinese Sea. At the same time there are numerous level-topped areas of loess of great size all over northwestern China which indicate deposition by water.

The same is true of the loess in the Mississippi and Missouri valleys. While it is doubtless true that in many places the accumulations are due to wind, it is equally evident that there are many level-topped areas of loess along the borders of the Missouri which betoken the height reached by the overflowing floods of the stream when, as already shown, it was gorged by silt-laden water from the melting ice in the closing stages of the glacial period. Both wind and water had their share in the distribution. The absence of true

water species of shells in the loess is what we should expect in an accumulation which took place in periodical or annual overflows. Land snails still love the flood-plains of variable streams. In the vicissitudes of the last stages of the glacial period we have the temporary presence of water provided for to suit the habits of such shells as are found in the loess.

FIG. 120.—Deep gulley in the loess at Helena, Arkansas. Courtesy of U. S. Geo. Survey. Photo. by A. F. Crider.

CHAPTER XVII.

FLIGHT OF PLANTS AND ANIMALS DURING THE GLACIAL AGE.

Among the most interesting incidental effects of the Glacial period is that of its influence in distributing plants and animals over the lower latitudes. A glance at a polar projection of the northern hemisphere shows to what a remarkable extent the land is clustered around the north pole, and how easy it would have been, under favorable conditions of climate, for plants and animals to spread from that vicinity along different meridians, till, in the lower latitudes, they should be on opposite sides of the earth. In conformity with these natural lines of emigration, it has long been known that both among plants and animals the species of the northern hemisphere are much more closely allied than those of the southern hemisphere, where no such land-connection exists; and, as we shall presently see, the problem presented by the distribution of plants in the northern hemisphere is very complex and curious. For its solution we are largely indebted to the sagacity of the late Professor Asa Gray, who discovered the key in the influence of the Glacial period.

In 1857, after he was already familiar, from private correspondence, with Darwin's theory of the origin of species, Professor Gray was called upon to study the extensive botanical collections brought back from Japan by the expeditions of Commodores Perry and Rodgers. Comparison of these species with those in corresponding latitudes in other portions of the world brought out clearly—what had been

before but dimly perceived—that there was a remarkable resemblance between the existing plants of eastern Asia and those of eastern North America, that more species are common to Japan and Europe than to Japan and western North

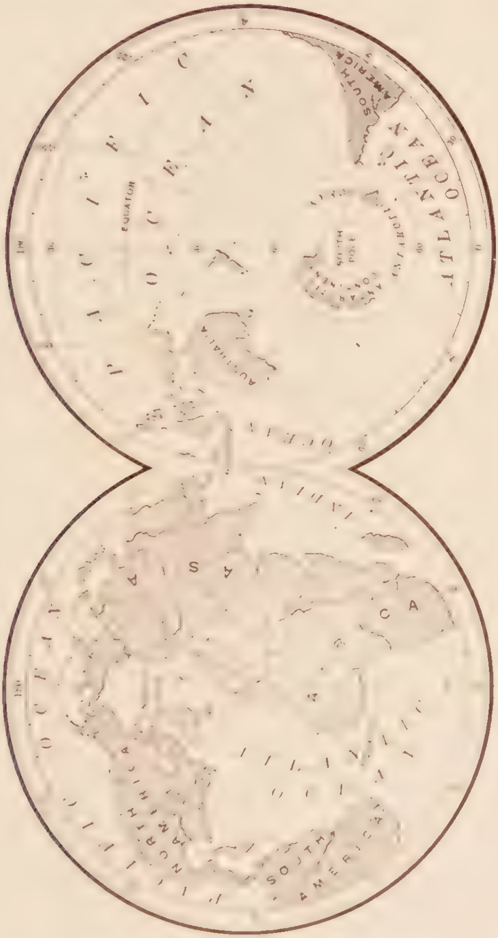

Fig. 121.—Map showing how the land clusters about the North Pole.

America, and that the resemblance is greatest of all between Japan and eastern North America. Out of three hundred species, common to the temperate regions of eastern Asia

and the corresponding region of North America, only one third is represented in western North America.

The key applied by Professor Gray for the solution of this problem was suggested by the investigations of Heer and others, which had brought out the fact that, during the Tertiary period, just before the beginning of the Ice age, a temperate climate, corresponding to that of latitude 35° on the Atlantic coast, extended far up toward the north pole, permitting Greenland and Spitzbergen to be covered with trees and plants similar, in most respects, to those found at the present time in Virginia and North Carolina. Here, indeed, in close proximity to the north pole, were then residing, in harmony and contentment, the ancestors of nearly all the plants and animals which are now found in the north temperate zone, and here they would have continued to stay but for the cold breath of the approaching Ice age, which drove them from their homes, and compelled them to migrate to more hospitable latitudes.

The picture of the flight and dispersal of these forests, and of their struggle to find, and adjust themselves to, other homes, is second in interest to that of no other migration. A single tree is helpless before such a force as an advancing glacier, since a tree alone can not migrate. But a forest of trees can. Trees can "take to the woods" when they can do nothing else, and so escape unfavorable conditions. There is a natural climatic belt to which the life of a forest is adjusted. In the present instance, as the favorable conditions near the poles were disturbed by the cooling influences of the glacier approaching from the north, the individual trees on that side of the forest-belt gradually perished; but, at the same time that the favorable conditions of life were contracting on the north, they were expanding on the south, so that along the southern belt the trees could gradually advance into new territory, and so the whole forest-belt move southward, following the conditions favorable to its existence. It is therefore easy to conceive how, with the slow advance of the glacial conditions from the north, the

vegetation of Greenland and British America was transferred far down toward the torrid zone on both the Eastern and the Western Continent. Being once thus transferred, the forest would be compelled to remain there until the retreat of the ice began again to modify the conditions so as to compel a corresponding retreat of plants toward their original northern habitat. Thus it is that these descendants of the preglacial plants of Greenland, arrested in their northward march, have remained the characteristic flora of the latitudes near the glacial boundary. On the other hand, the arctic species, which can not endure even a temperate climate, and which must have accompanied the advancing glacier southward, found their natural conditions again in two ways: 1. By following closely upon the steps of the retreating ice to extreme northern latitudes; and, 2. To use Professor Gray's happy expression, by "taking to the mountains," and finding near their summits the necessary arctic conditions. It is thus that the mountains of New England and Labrador contain many species of plants nearly identical with those on the Alps in Europe.

No better presentation of this subject can be given than that of Professor Gray himself, made in an address delivered in 1878, and which by the kindness of Mrs. Gray I am permitted in large part to reproduce in this connection: *

The forests of the whole northern hemisphere in the temperate zone (those that we are concerned with) are mainly made up of the same or similar *kinds*. Not of the same species, for rarely do identical trees occur in any two or more widely separated regions; but all round the world in our zone the woods contain pines and firs and larches, cypresses and junipers, oaks and birches, willows and poplars, maples and ashes, and the like. Yet, with all these family likenesses throughout, each region has some peculiar features, some trees by which the country may at once be distinguished.

* "Forest Geography and Archæology," a lecture delivered before the Harvard University Natural History Society, April 18, 1878, by Asa Gray. Printed in the "American Journal of Science," vol. cxvi, pp. 85–94, 183–196.

Beginning by a comparison of our Pacific with our Atlantic forests, it is to be noted that the greater part of the trees familiar on the Atlantic side of the continent are conspicuously absent from the Pacific forests.

For example, the Pacific coast has no magnolias, no tulip-tree, no papaw, no linden or basswood, and is very poor in maples; no locust-trees—neither flowering locust nor honey-locust—nor any leguminous tree; no cherry large enough for a timber-tree, like our wild black cherry; no gum-trees (*Nyssa* nor Liquidambar), nor sorrel-tree, nor kalmia; no persimmon, or bumelia; not a holly; only one ash that may be called a timber-tree; no catalpa or sassafras: not a single elm, nor hackberry; not a mulberry, nor planer-tree, nor maclura; not a hickory, nor a beech, nor a true chestnut, nor a hornbeam; barely one birch-tree, and that only far north, where the differences are less striking. But as to coniferous trees, the only missing type is our bald cypress—the so-called cypress of our Southern swamps—and that deficiency is made up by other things. But as to ordinary trees, if you ask what takes the place in Oregon and California of all these missing kinds, which are familiar on our side of the continent, I must answer nothing, or nearly nothing. There is the madroña (Arbutus) instead of our kalmia (both really trees in some places); and there is the California laurel instead of our Southern red bay-tree. Nor in any of the genera common to the two does the Pacific forest equal the Atlantic in species. It has not half as many maples, nor ashes, nor poplars, nor walnuts, nor birches, and those it has are of smaller size and of inferior quality; it has not half as many oaks, and these and the ashes are of so inferior economic value that (as we are told) a passable wagon-wheel can not be made of California wood, nor a really good one in Oregon. . . .

Now almost all these recur, in more or less similar but not identical species, in Japan, north China, etc. Some of them are likewise European, but more are not so. Extending the comparison to shrubs and herbs, it more and more appears that the forms and types which we count as peculiar to our Atlantic region, when we compare them, as we first naturally

do, with Europe and with our West, have their close counterparts in Japan and north China; some in identical species (especially among the herbs), often in strikingly similar ones, not rarely as sole species of peculiar genera or in related generic types. I was a very young botanist when I began to notice this, and I have from time to time made lists of such instances. Evidences of this remarkable relationship have multiplied year after year, until what was long a wonder has come to be so common that I should now not be greatly surprised if a Sarracenia or a *Dionæa*, or their like, should turn up in eastern Asia. Very few such isolated types remain without counterparts. It is as if Nature, when she had enough species of a genus to go round, dealt them fairly, one at least to each quarter of our zone; but when she had only two of some peculiar kind gave one to us and the other to Japan, Manchuria, or the Himalayas; when she had only one, divided these between the two partners on the opposite side of the table. As to number of species generally, it can not be said that Europe and Pacific North America are at all in arrears; but, as to trees, either the contrasted regions have been exceptionally favored or these have been hardly dealt with. There is, as I have intimated, some reason to adopt the latter alternative.

We may take it for granted that the indigenous plants of any country, particularly the trees, have been selected by climate. Whatever other influences or circumstances have been brought to bear upon them, or the trees have brought to bear on each other, no tree could hold its place as a member of any forest or flora which is not adapted to endure even the extremes of the climate of the region or station. But the character of the climate will not explain the remarkable paucity of the trees which compose the indigenous European forest. That is proved by experiment, sufficiently prolonged in certain cases to justify the inference. Probably there is no tree of the northern temperate zone which will not flourish in some part of Europe. Great Britain alone can grow double or treble the number of trees that the Atlantic States can; in all the latter we can grow hardly one tree of the Pacific coast. England supports all of them, and all our Atlantic trees also, and likewise the Japanese and north Siberian species, which do thrive

here remarkably in some parts of the Atlantic coast, especially the cooler temperate ones. The poverty of the European *sylva* is attributable to the absence of our Atlantic American types, to its having no magnolia, liriodendron, asimina, negundo, no Æschulus, none of that rich assemblage of leguminous trees represented by locusts, honey-locusts, gymnocladus, and cladrastis (even its cercis, which is hardly European, is like the Californian one mainly a shrub); no *Nyssa*, nor Liquidambar; no *Ericaceæ* rising to a tree; no bumelia, catalpa, sassafras, Osage orange, hickory, or walnut; and, as to conifers, no hemlock, spruce, arbor-vitæ, taxodium, nor Torreya. As compared with northeastern Asia, Europe wants most of these same types, also the ailantus, gingko, and a goodly number of coniferous genera. I can not point to any types tending to make up the deficiency—that is, to any not either in east North America or in northeast Asia, or in both. Cedrus, the true cedar, which comes near to it, is only north African and Asian. I need not say that Europe has no *Sequoia*, and shares no special type with California.

Now, the capital fact is, that many and perhaps almost all of these genera of trees were well represented in Europe throughout the later Tertiary times. It had not only the same generic types, but in some cases even the same species, or what must pass as such, in the lack of recognizable distinctions between fossil remains and living analogues. Probably the European Miocene forest was about as rich and various as is ours of the present day, and very like it. The Glacial period came and passed, and these types have not survived there, nor returned. Hence the comparative poverty of the existing European *sylva*, or at least the probable explanation of the absence of those kinds of trees which make the characteristic difference.

Why did these trees perish out of Europe, but survive in America and Asia? Before we inquire how Europe lost them, it may be well to ask how it got them. How came these American trees to be in Europe? And among the rest, how came Europe to have *Sequoias*, now represented only by our two big trees of California? It actually possessed two species and more; one so closely answering to the redwood of the Coast

Ranges, and another so very like the *Sequoia gigantea* of the Sierra Nevada, that, if such fossil twigs with leaves and cones had been exhumed in California instead of Europe, it would confidently be affirmed that we had resurrected the veritable ancestors of our two giant trees. Indeed, so it may probably be. *Cœlum non animum mutant*, etc., may be applicable even to such wide wanderings and such vast intervals of time. If the specific essence has not changed, and even if it has suffered some change, genealogical connection is to be inferred in all such cases. . . .

I take it that the true explanation of the whole problem comes from a just general view, and not through piecemeal suppositions of chances. And I am clear that it is to be found by looking to the north, to the state of things at the arctic zone—first, as it now is, and then as it has been.

North of our forest regions comes the zone unwooded from cold, the zone of arctic vegetation. In this, as a rule, the species are the same round the world; as exceptions, some are restricted to a part of the circle.

The polar projection of the earth down to the northern tropic shows to the eye—as our maps do not—how all the lands come together into one region, and how natural it may be for the same species, under homogeneous conditions, to spread over it. When we know, moreover, that sea and land have varied greatly since these species existed, we may well believe that any ocean-gaps, now in the way of equable distribution, may have been bridged over. There is now only one considerable gap.

What would happen if a cold period were to come on from the north, and were very slowly to carry the present arctic climate, or something like it, down far into the temperate zone? Why, just what has happened in the Glacial period, when the refrigeration somehow pushed all these plants before it down to southern Europe, to middle Asia, to the middle and southern part of the United States; and, at length receding, left some part of them stranded on the Pyrenees, the Alps, the Apennines, the Caucasus, on our White and Rocky Mountains, or wherever they could escape the increasing warmth as well by ascending mountains as by receding northward at lower levels. Those

that kept together at a low level, and made good their retreat, form the main body of present arctic vegetation. Those that took to the mountains had their line of retreat cut off, and hold their positions on the mountain-tops under cover of the frigid climate due to elevation. The conditions of these on different continents or different mountains are similar but not wholly alike. Some species proved better adapted to one, some to another, part of the world: where less adapted, or less adaptable, they have perished; where better adapted, they continue—with or without some change—and hence the diversification of Alpine plants as well as the general likeness through all the northern hemisphere.

All this exactly applies to the temperate-zone vegetation, and to the trees that we are concerned with. The clew was seized when the fossil botany of the high arctic regions came to light; when it was demonstrated that in the times next preceding the Glacial period—in the latest Tertiary—from Spitzbergen and Iceland to Greenland and Kamchatka, a climate like that we now enjoy prevailed, and forests like those of New England and Virginia, and of California, clothed the land. We infer the climate from the trees; and the trees give sure indications of the climate.

I had divined and published the explanation long before I knew of the fossil plants. These, since made known, render the inference sure, and give us a clear idea of just what the climate was. At the time we speak of, Greenland, Spitzbergen, and our arctic sea-shore, had the climate of Pennsylvania and Virginia now. It would take too much time to enumerate the sorts of trees that have been identified by their leaves and fruits in the arctic later Tertiary deposits.

I can only say, at large, that the same species have been found all round the world; that the richest and most extensive finds are in Greenland; that they comprise most of the sorts which I have spoken of, as American trees which once lived in Europe—magnolias, sassafras, hickories, gum-trees, our identical Southern cypress (for all we can see of difference), and especially *Sequoias*—not only the two which obviously answer to the two big trees now peculiar to California, but several others; that they equally comprise trees now peculiar to

Japan and China, three kinds of gingko-trees, for instance, one of them not evidently distinguishable from the Japan species which alone survives: that we have evidence not merely of pines and maples, poplars, birches, lindens, and whatever else characterize the temperate-zone forests of our era, but also of particular species of these, so like those of our own time and country, that we may fairly reckon them as the ancestors of several of ours. Long genealogies always deal more or less in conjecture; but we appear to be within the limits of scientific inference when we announce that our existing temperate trees came from the north, and within the bounds of high probability when we claim not a few of them as the originals of present species. Remains of the same plants have been found fossil in our temperate region, as well as in Europe.

Here, then, we have reached a fair answer to the question how the same or similar species of our trees came to be so dispersed over such widely separated continents. The lands all diverge from a polar center, and their proximate portions—however different from their present configuration and extent, and however changed at different times—were once the home of those trees, when they flourished in a temperate climate. The cold period which followed, and which doubtless came on by very slow degrees during ages of time, must long before its culmination have brought down to our latitudes, with the similar climate, the forest they possess now, or rather the ancestors of it. During this long (and we may believe first) occupancy of Europe and the United States, were deposited in pools and shallow waters the cast leaves, fruits, and occasionally branches, which are imbedded in what are called Miocene Tertiary, or later deposits, most abundant in Europe, from which the American character of the vegetation of the period is inferred. Geologists give the same name to these beds in Greenland and southern Europe, because they contain the remains of identical and very similar species of plants; and they used to regard them as of the same age on account of this identity. But in fact this identity is good evidence that they can not be synchronous. The beds in the lower latitudes must be later, and were forming when Greenland probably had very nearly the climate which it has now.

Wherefore the high, and not the low, latitudes must be assumed as the birthplace of our present flora, and the present arctic vegetation is best regarded as derivative of the temperate. This flora, which, when circumpolar, was as nearly homogeneous round the high latitudes as the arctic vegetation is now, when slowly translated into lower latitudes, would preserve its homogeneousness enough to account for the actual distribution of the same and similar species round the world, and for the original endowment of Europe with what we now call American types. It would also vary or be selected from by the increasing differentiation of climate in the divergent continents and on their different sides in a way which might well account for the present diversification. From an early period the system of the winds, the great ocean-currents (however they may have oscillated north and south), and the general proportions and features of the continents in our latitude (at least, of the American Continent), were much the same as now, so that species of plants, ever so little adapted or predisposed to cold winters and hot summers, would abide and be developed on the eastern side of continents, therefore in the Atlantic United States and in Japan and Manchuria: those with preference for milder winters would incline to the western sides; those disposed to tolerate dryness would tend to interiors or to regions lacking summer rain. So that, if the same thousand species were thrust promiscuously into these several districts, and carried slowly onward in the way supposed, they would inevitably be sifted in such a manner that the survival of the fittest for each district might explain the present diversity.

Besides, there are resiftings to take into the account. The Glacial period or refrigeration from the north, which at its inception forced the temperate flora into our latitude, at its culmination must have carried much or most of it quite beyond. To what extent displaced, and how far superseded by the vegetation which in our day borders the ice, or by ice itself, it is difficult to form more than general conjectures, so different and conflicting are the views of geologists upon the Glacial period. But upon any, or almost any, of these views it is safe to conclude that temperate vegetation, such as preceded the refrigeration, and has now again succeeded it, was either thrust

out of northern Europe and the northern Atlantic States or was reduced to precarious existence and diminished forms. It also appears that, on our own continent at least, a milder climate than the present, and a considerable submergence of land, transiently supervened at the north, to which the vegetation must have sensibly responded by a northward movement, from which it afterward receded.

All these vicissitudes must have left their impress upon the actual vegetation, and particularly upon the trees. They furnish probable reason for the loss of American types sustained by Europe.

I conceive that three things have conspired to this loss: 1. Europe, hardly extending south of latitude 40°, is all within the limits generally assigned to severe glacial action. 2. Its mountains trend east and west, from the Pyrenees to the Carpathians and the Caucasus beyond, near its southern border; and they had glaciers of their own, which must have begun their operations, and poured down the northward flanks, while the plains were still covered with forest on the retreat from the great ice-wave coming from the north. Attacked both on front and rear, much of the forest must have perished then and there. 3. Across the line of retreat of those which may have flanked the mountain-ranges, or were stationed south of them, stretched the Mediterranean, an impassable barrier. Some hardy trees may have eked out their existence on the northern shore of the Mediterranean and the Atlantic coast. But, we doubt not, taxodium and *Sequoias*, magnolias, and Liquidambars, and even hickories and the like, were among the missing. Escape by the east, and rehabilitation from that quarter until a very late period, was apparently prevented by the prolongation of the Mediterranean to the Caspian, and thence to the Siberian Ocean. If we accept the supposition of Nordenskiöld, that, anterior to the Glacial period, Europe was "bounded on the south by an ocean extending from the Atlantic over the present deserts of Sahara and central Asia to the Pacific," all chance of these American types having escaped from or re-entered Europe from the south and east is excluded. Europe may thus be conceived to have been for a time somewhat in the condition in which Greenland is now,

and, indeed, to have been connected with Greenland in this or in earlier times. Such a junction, cutting off access of the Gulf Stream to the Polar Sea, would, as some think, other things remaining as they are, almost of itself give glaciation to Europe. Greenland may be referred to, by way of comparison, as a country which, having undergone extreme glaciation, bears the marks of it in the extreme poverty of its flora, and in the absence of the plants to which its southern portion, extending six degrees below the Arctic Circle, might be entitled. It ought to have trees, and might support them. But, since destruction by glaciation, no way has been open for their return. Europe fared much better, but suffered in its degree in a similar way.

Turning for a moment to the American Continent for a contrast, we find the land unbroken and open down to the tropic, and the mountains running north and south. The trees, when touched on the north by the on-coming refrigeration, had only to move their southern border southward, along an open way, as far as the exigency required; and there was no impediment to their due return. Then the more southern latitude of the United States gave great advantage over Europe. On the Atlantic border, proper glaciation was felt only in the northern part, down to about latitude 40°. In the interior of the country, owing doubtless to greater dryness and summer heat, the limit receded greatly northward in the Mississippi Valley, and gave only local glaciers to the Rocky Mountains; and no volcanic outbreaks or violent changes of any kind have here occurred since the types of our present vegetation came to the land. So our lines have been cast in pleasant places, and the goodly heritage of forest-trees is one of the consequences.

The still greater richness of northeastern Asia in arboreal vegetation may find explanation in the prevalence of particularly favorable conditions, both ante-glacial and recent. The trees of the Miocene circumpolar forest appear to have found there a secure home; and the Japanese Islands, to which most of these trees belong, must be remarkably adapted to them. The situation of these islands—analogous to that of Great Britain, but with the advantage of lower latitude and greater

sunshine—their ample extent north and south, their diversified configuration, their proximity to the great Pacific Gulf Stream, by which a vast body of warm water sweeps along their accentuated shores, and the comparatively equable diffusion of rain throughout the year, all probably conspire to the preservation and development of an originally ample inheritance.

The case of the Pacific forest is remarkable and paradoxical. It is, as we know, the sole refuge of the most characteristic and wide-spread type of Miocene *Coniferæ*, the *Sequoias*; it is rich in coniferous types beyond any country except Japan; in its gold-bearing gravels are indications that it possessed, seemingly down to the very beginning of the Glacial period, Magnolias and beeches, a true chestnut, Liquidambar, elms, and other trees now wholly wanting to that side of the continent, though common both to Japan and to Atlantic North America. Any attempted explanation of this extreme paucity of the usually major constituents of forest, along with a great development of the minor or coniferous element, would take us quite too far, and would bring us to mere conjectures.

Much may be attributed to late glaciation; something to the tremendous outpours of lava which, immediately before the period of refrigeration, deeply covered a very large part of the forest area; much to the narrowness of the forest-belt, to the want of summer rain, and to the most unequal and precarious distribution of that of winter.

Upon all these topics questions open which we are not prepared to discuss. I have done all I could hope to do in one lecture if I have distinctly shown that the races of trees, like the races of men, have come down to us through a prehistoric (or pre-natural-historic) period; and that the explanation of the present condition is to be sought in the past, and traced in vestiges, and remains, and survivals; that for the vegetable kingdom also there is a veritable archæology.

As the truth of a theory needs to be tested by the method of difference as well as of agreement, we turn to inquire if it be not true that all mountains which reach above the snow-line have an Alpine flora, and whether it be not the conditions themselves which determine the peculiarities?

These questions are answered by an appeal to certain oceanic islands which were outside the influence of continental glaciation. According to Wallace, a striking proof of the theory presented by Professor Gray "is found on the Peak of Teneriffe, a mountain 12,000 feet high. In the uppermost 4,500 feet of this mountain above the limit of trees, Von Buch found only eleven species of plants, eight of which were peculiar; but the whole were allied to those found at lower elevations. On the Alps or Pyrenees, at this elevation, there would be a rich flora comprising hundreds of arctic plants; and the absence of anything corresponding to them in this case, in which their ingress was cut off by the sea, is exactly what the theory leads us to expect."*

On both continents, at the close of the Tertiary period, there occurred a remarkable extinction of animals which is doubtless connected with the advance of the continental ice-sheet. Among these we may mention two species of the cat family as large as lions; four species of the dog family, some of them larger than wolves; two species of bears; a walrus, found in Virginia; three species of dolphins, found in the Eastern States; two species of the sea-cow, found in Florida and South Carolina; six species of the horse; the existing South American tapir; a species of the South American llama; a camel; two species of bison; three species of sheep; two species of elephants and two of mastodons; a species of Megatherium, three of Megalonyx, and one of Mylodon—huge terrestial sloths as large as the rhinoceros, or even as large as elephants, which ranged over the Southern States to Pennsylvania, and the Mylodon as far as the Great Lakes and Oregon.†

This wondrous assemblage of animals became extinct upon the approach of the Glacial period, as their remains are all found in post-Pliocene deposits. The intermingling of forms is remarkable. The horses, camels, and elephants which

* "The Geographical Distribution of Animals," vol. i, p. 43.

† Ibid., p. 129.

lived in North America before the Glacial period were found subsequent to the Glacial period only in the Old World, while the llamas, tapirs, and gigantic *Edendata* are South American types. The progress of events seems to have been about as follows: In the warm period preceding the Glacial epoch, when the vegetation of the temperate zone flourished about the north pole, there was land connection between the continents, permitting the larger species of the Old World to migrate to North America. At the same time the conditions in North America were favorable to the tropical species of animals which had developed and flourished in South America. The refrigeration of the climate on the approach of the Glacial period, and the advance of the ice from the north, cut off retreat to the Old World species, and gradually hemmed them in over the southern portion of the continent, where all forms of life were compelled to readjust themselves to new conditions. The struggle for existence probably resulted, first, in the extinction of those South American species which had invaded North America during the warmer climate of later Tertiary times; and the more hardy emigrants from the north would have the advantage from the similarity in climate in the southern United States during the Glacial period to that about the poles, where they had flourished immediately before. With the withdrawal of ice to the north, the struggle of these animals with the condition of existence began anew, and the mammoth and some others found themselves unable to cope with the changes to which they were compelled to adjust themselves. From the abundance of remains of these animals found in the peat-bogs of kettle-holes and in the glacial terraces of gravel and loess, it is evident that they followed close upon the retreating ice-front, and some of them continued the retreat to the Arctic Circle, where they still live and flourish; while others, like the elephant and mastodon, perished.

Few things are better calculated to impress the scientific imagination than this dispersion and final extinction in North America of so many large animals native to the Old World;

while some of them, like the horse, were admirably adapted to the present conditions, as is shown by their rapid increase since their introduction after the discovery of America by the whites. In a succeeding chapter we shall also see that man himself participated in this struggle with the new conditions introduced by the Glacial period on this continent, and that, in company with the mammoth, walrus, and other arctic species, he followed up the retreating ice both upon the Atlantic coast and in the Mississippi Valley. Whether, like some of his companions, he was unsuccessful in the contest is not certain, though there is much to be said in favor of the theory that the Eskimos of the north are the lineal descendants of the preglacial men whose implements are found in New Jersey, Ohio, and Minnesota. Much also may be said to support the theory, alluded to by Professor Claypole, connecting the traditions of the destruction of large portions of the human race by a flood with the extermination of species naturally brought about by the conditions accompanying the floods which closed the Glacial period.

It is interesting to observe, also, that insects as well as plants and the larger animals were compelled to reckon with the Glacial period. They, too, participated in the southern migration enforced by the advancing ice, and also shared in the vicissitudes of its final retreat, compelling them to escape from the warmer belt of climate which again advanced upon them from the south. Like the forms of arctic and Alpine vegetation, a portion of the insects also took to the mountains, where they still remain, as living witnesses to the reality of the Glacial period. The summits of the White Mountains are characterized by Alpine species of insects, one of which is thus described by Mr. Samuel Scudder:

But even the narrow limit of the Alpine zone of the White Mountains claims for its own a single butterfly, which probably has a more restricted range than any other in the world. One may search the season through over the comparatively vast and almost equally barren elevations within the sub-Alpine district of the White Mountains and fail to discover more than here

and there a solitary individual whirled by fierce blasts down the mountain-slopes, while, a few hundred feet above, the butterflies swarm in great numbers. Every passage of the sun from behind a cloud brings them out in scores, and they may often be captured as fast as they can be properly secured. The contrast between the occasional and unwilling visitor in the sub-Alpine region and the swarms which flutter about the upper plateaus is most significant. Yet the *Carices*, the food-plant of the caterpillar, are quite as abundant in the lower regions as in the upper, even to the species *C. rigida*, upon which I found the larva feeding. Now, this butterfly (*Œneis semidea*) belongs to a genus which is peculiar to Alpine and arctic regions; in fact, it is the only genus of butterflies which is exclusively confined to them. It has numerous members, both in this country and in the Old World. One is confined to the Alps of Europe; most of the European species, however, are found only in the extreme north. The genus extends across the whole continent of America, and several of its species occur on the highest elevations of the Rocky Mountains. Several species are common to Europe and America, and it is to one of these that *Œneis semidea* is most closely allied. A few species descend into the Hudsonian fauna, but, as a whole, the genus has its metropolis farther north. So that, in ascending Mount Washington, we pass, as it were, from New Hampshire to northern Labrador; on leaving the forests, we come first upon animals recalling those of the northern shores of the Gulf of St. Lawrence and the coast of Labrador opposite Newfoundland; and, when we have attained the summit, we find insects which represent the fauna of Atlantic Labrador and the southern extremity of Greenland.*

Commenting upon these and similar facts connected with other species of butterflies and with several species of moths, Mr. A. R. Grote pertinently says: †

The question comes up with regard to the White Mountain butterfly, as to the manner in which this species of *Œneis*

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* "Geology of New Hampshire," vol. i, pp. 340, 341.

† "American Journal of Science," vol. cx, 1875, pp. 337, 338.

attained its present restricted geographical area. . . . How did the White Mountain butterfly get up the White Mountains? I am disposed to answer, by the action attendant on the decline of the Glacial period. . . .

The main ice-sheet had pushed them insensibly before it, and, during the continuance of the Glacial period, the geographical distribution of the genus *Œneis* had been changed from a high northern region to one which may well have included portions of the Southern States. And, on its decline, the ice-sheet drew them back again after itself by easy stages; yet not all of them. Some of these butterflies strayed by the way, detained by the physical nature of the country, and destined to plant colonies apart from their companions. When the main ice-sheet left the foot of the White Mountains, on its long march back to the pole, where it now seems to rest, some of these wayward, flitting *Œneis* butterflies were left behind. These had strayed up behind the local glaciers on Mount Washington, and so became separated from the main body of their companions, which latter journeyed northward, following the course of the retirement of the main ice-sheet. They had found in elevation their congenial climate, and they have followed this gradually to the top of the mountain, which they have now attained, and from which they can not now retreat. Far off in Labrador the descendants of their ancestral companions fly over wide stretches of country, while they appear to be in prison on the top of a mountain. I conceive that in this way the mountains may generally have secured their Alpine animals. The Glacial period can not be said strictly to have expired. It exists even now for high levels above the sea, while the Eskimos find it yet enduring in the far north. Had other conditions been favorable, we might now find arctic man living on snow-capped mountains within the temperate zone.

At a height of from 5,600 to 6,200 feet above the level of the sea, and a mean temperature of about 48° during a short summer, the White Mountain butterflies (*Œneis semidea*) yet enjoy a climate like that of Labrador within the limits of New Hampshire. And in the case of moths an analogous state of things exists. The species *Anarta melanopa* is foun on Mount

Washington, the Rocky Mountains, and in Labrador. *Agrotis Islandica* is found in Iceland, Labrador, in the White Mountains, and perhaps in Colorado. As on islands in the air, these insects have been left by the retiring ice-flood during the opening of the Quaternary.

On inferior elevations, as on Mount Katahdin, in Maine, where we now find no *Œneis* butterflies, these may formerly have existed, succumbing to a climate gradually increasing in warmth from which they had no escape; while the original colonization, in the several instances, must have always greatly depended upon local topography.

In a Russian Government Report made in 1900, is found a list of plants occurring in the provinces of Okhotsk and Kamchatka. This list contains 746 species of phaenogamous or flowering plants, 173 identical species of which are common to North America, that is, twenty-three per cent are found in North America. Many of these species are distributed universally through the North Temperate Zone, and twenty-one are known to have been introduced into America from Europe, but have become naturalized. If now we compare the flora of Manchuria, using the list published in the Russian Government Report on Manchuria for 1897, with that on Kamchatka and Okhotsk for 1900, we find that there are 193 identical species common to both, that is, nearly twenty-six per cent, only five per cent more than that with North America. Of the 173 species common to North America and the Provinces of Okhotsk and Kamchatka, seventy-seven are also found in Manchuria. Out of the 284 genera found in Okhotsk and Kamchatka there are sixty-two genera not to be found in North America. This number will probably be increased when the Kamchatkan flora has been better studied, for the region is so inaccessible that the lists at present must be quite incomplete.

The following list gives the plants common to the Okhotsk-Kamchatkan region and North America, those marked with a (*) are common to Manchuria also.

Anemone pennsylvanica, L.
*A. nemorosa, L.
A. parviflora, Mich.
Ranunculus Flammula, L.
R. Cymbalariæ, Purch.
*R. repens, L.
Caltha palustris, L.
Coptis trifolia, Salsb.
Actaea spicata, L.
Chelidonium majus, L.
Dicentra lachenaliaeflora, Ldb.
Nasturcium palustre, Leyss.
*Barbarea vulgaris, R. Br.
Arabis hirsuta, Scop.
Cardamine bellidifolia, L.
C. pratensis, L.
Draba incana, L.
*D. nemorosa, L.
*Thlaspi arvense, L.
*Capsella Birsa pastoris, L.
*Sisymbrium Sophia, L.
*Erysimum cheiranthoides, L.
Viola palustris, L.
V. blanda, Hook.
*V. canina, L.
Drosera rotundifolia, L.
*Stellaria media, Willd.
*S. borealis, MB.
S. humifusa, Rot.
*S. longifolia, Muhl.
*S. longipes, Gold.
Cerastium vulgatum, L.
*C. arvense, L.
Linum perenne, L.
*Geranium sibiricum, L.
*Oxalis Acetosella, L.
Trifolium medium, L.
T. pratense, L.
Oxytropis campestris, D.C.
Astragalus alpinus, L.
*Vicia cracca, L.
*Lathyrus palustris, L.
L. pratensis, L.
*Spiraea betulifolia, L.
*S. salicifolia, L.
*Gum strictum, Ait.
G. macrophyllum, Willd.
Potentilla norvegica, L.
P. Anserina, L.
*P. fruticosa, L.
*Fragaria vesca, L.
Pyrus sambucifolia, Cham. et Schlect.
*Epilobium angustifolium, L.
Hippuris vulgaris, L.
Claytonia virginica, L.
Sedum Rhodiola, D.C.
*Ribes rubrum, L.
Saxifraga oppositifolia, L.
*Chrysosplenium alternifolia, L.
Mitella nuda, L.
Ligusticum scoticum, L.
Coelopleurum Gmelini, Ldb.
Carum carui, L.
Cornus canadensis, L
*Adoxa Moschatellina, L.
*Sambucus racemosa, L.
*Linnea borealis, L.
*Galium Aparine, L.
G. trifidum, L.
*G. verum. L.
*Erigeron acris, L.
Solidago Virgaurea, L.
*Achillea millefolium, L.

A. Ptarmica, L.
Matricaria discoidea, D.C.
Tanacetum vulgare, L.
Artemisia biennis, Willd.
A. Stelleriana, Bess.
*Gnaphalium ugliginosum, L.
*Senecio pseudo-Arnica, Less.
*Picris hieracioides, L.
*Taraxacum officinale, Wigg.
Crepis tectorum, L.
*Vaccinium Vitis-Idaea, L.
V. uliginosum, L.
Arctostaphylus alpina, Sprgl.
A. uva ursi, Sprgl.
Andromeda polifolia, L.
Phyllodoce taxifolia, Salsb.
Loiseuria procumbens, Desv.
*Ledum palustre, L.
*Pyrola rotundifolia, L.
P. minor, L.
P. secunda, L.
*Moneses grandiflora, Salsb.
*Utricularia intermedia, Hayne.
Primula farinosa, L.
*Lysimachia thyrsiflora, L.
Samolus Valerandi, L.
Gentiana Amarella. L.
*Menyanthes trifoliata, L.
*Polemonium coeruleum, L.
*Mertensia maritima, G. Don.
*Echinospermum Lappula, Lehm.
*E. deflexum, Lehm.
Limostella aquatica, L.
Veronica Anagallis, L.
V. serpyllifolia, L.
Castelleja pallida, Kunt.
*Euphrasia officinalis, L.
*Mentha arvensis, L.
Thumus Serpyllum, L.
*Nepeta Glechoma, Benth.
Scutellaria galericulata, L.
Galeopsis Tetrahit, L.
*Plantago major, L.
*Rumex acetosa, L.
*Polygonum Bistorta, L.
*P. viviparum, L.
*P. aviculare, L.
P. convolvolus, L.
Empertum nigrum, L.
Salix phylicifolia, L.
*S. myrtilloides, L.
*Populus tremula, L.
*P. alba, L.
*Humulus Lupulus, Ldb.
*Urtica dioica, L.
*Alnus incana, Willd.
Myrica Gale, L.
*Juniperus communis, L.
*Chenopodium album, L.
Atriplex patula, L.
Sparganium simplex, Huds.
Acorus calamus, L.
Zostera marina, L.
Potamogeton praelongus. Wulf.
P. perfoliatus, L.
Triglochin palustris, L.
Alisma plantago, L.
Corallorhiza innata, R. Br.
*Microstylis monophylla, Lindl.
Calypso borealis, Salisb.
Streptopus amplexifolius, D.C.

Smilicina trifolia, Desv.
Allium Schoenoprasum, L.
*Veratrum viride, Ait.
Luzula spadicea.
*L. campestris, D.C.
Juncus balticus, Dethar.
J. filiformis, L.
J. articulatus, L.
Eriophorum vaginatum, L.
Carex alpina, Sw.
C. vulgaris, Fries.
*C. stenophylla, Wahl.
C. rariflora, Smit.
*Elymus mollis, Trin.
Festuca ovina, L.
Poa laxa, Henke.
*P. pratensis, L.
P. compressa, L.
P. serotina, Ehrh.
*P. nemoralis, L.
P. annua, L.
*Hierochloa borealis, R. et Sch.
*Equisetum pratense, Chrk.
E. limosum, L.
*E. silvaticum, L.
E. variegatum, Sehleich.
E. scirpoides, Mich.
*E. arvense, L.
*E. hyemale, L.
Lycopodium Selago, L.
*L. annotinum, L.
*L. alpinum, L.
*L. complanatum, L.
*L. clavatum, L.
Selaginella rupestris, Spring.
H. alpina, R. et. Sch.
Deschampsia caespitosa, P. Bea.
Calamagrostis Langsdorffii, Trin.
Agrostis canina, L.
Trisetum subspicatum, Beanv.
*Phleum alpinum, L.
Cryptogamia
Botrychium Lunaria, Sw.
Polypodium vulgare, L.
*Woodsia ilvensis, R. Br.
W. glabella, R. Br.
Aspidum fragrans, Sw.
*Crystopteris fragilis, Bernh.
*Asplenium Folix-foemina, Bernh.
*Pteris aquillina, L.
*Adianthum pedatum, L.
Struthiopteris germanica, Willd.

MAP
showing
GLACIATED AREAS
IN NORTH AMERICA AND EUROPE.
Boundaries of Ice-Sheets.
Driftless Area of Wisconsin.
Courses of Glacial Striæ and transportation of Boulders.
Modified Drift in the lower Mississippi Valley.
PACIFIC OCEAN
ARCTIC OCEAN
NORTH POLE
ASIA
BRITISH AMERICA
ROCKY MOUNTAINS
UNITED STATES
MEXICO
GULF OF MEXICO
Tropic of Cancer
GULF OF CALIFORNIA
SIERRA NEVADA
HUDSON BAY
LABRADOR
LAURENTIAN HIGHLANDS
ALLEGHENY MTS
BAFFIN BAY
GREENLAND
Now PRINCIPALLY COVERED BY AN ICE-SHEET
Arctic Circle
ATLANTIC OCEAN
EUROPE
AFRICA
MEDITERRANEAN SEA
BLACK SEA
SCANDINAVIA
Mackenzie R.
Columbia R.
Colorado R.
Rio Grande
Red R.
Arkansas
Mississippi R.
Saskatchewan R.
Nelson R.
Ancient Glaciers

Fig. 122.

CHAPTER XVIII.

EUROPE DURING THE GLACIAL PERIOD.

At this point it will be profitable to take a survey of the condition of some other parts of the world during the great Ice age. By the same marks which determine the extent of the glacier in America, it is evident that the existing glaciers of Switzerland and Norway are but remnants of what formerly existed in these localities.

James Geikie's statement of the situation in the British Isles is sufficiently complete:

During the climax of the Glacial period all Scotland was drowned in a wide-spread *mer de glace*, which coalesced in the north and east with a similar sheet of ice, that crept outward from Scandinavia. To the west the Scottish ice, meeting with no impediment to its course, overflowed the outer Hebrides to a height of 1,600 feet, and probably continued on its path into the Atlantic as far as the edge of the 100-fathom plateau, where the somewhat sudden deepening of the sea would allow it to break off and send adrift whole argosies of icebergs. The height reached by the upper surface of the ice that overwhelmed the outer Hebrides enables us to ascertain the angle of slope between those islands and the mainland. This was 1 in 211—that is to say, the inclination of the surface of the ice-sheet was about twenty-five feet in the mile—an inclination which would appear to the eye almost like a dead level. . . .

The ice flowed off Ireland in all directions save to northeast in Antrim, upon the coast of which it encountered the Scottish *mer de glace*, which forced it to turn away to northwest and southeast; but along the whole western and southern shores,

where no obstacle to its passage intervened, it seems to have swept in one broad and continuous stream out—probably as far as that of Scotland—into the Atlantic. The thickness attained by the ice that flowed into the Irish Sea from Scotland, where it coalesced with the *mer de glace* coming from the eastern seaboard of Ireland, and also, as we shall presently see, with that creeping out from England and Wales, makes it quite certain that the area now occupied by that sea must at that time have been filled with glacier ice. . . .

The North Sea was filled with a massive *mer de glace* continually advancing in a general south-southwestern direction, the presence of which is distinctly traceable in the remarkable deflections of the glaciation all along the seaboard of Scotland from Stonehaven southward. It was simply owing to the superior elevation and extent of the Scottish mountains that the narrow strip of low-lying ground in the eastern maritime districts of that country was not invaded by an alien ice-stream. When we pass into England the hills become lower, and the area of low ground between the hills and the sea increases in breadth. There was thus less and less opposition offered to the southward advance of the North Sea *mer de glace* as it pressed upon the eastern shores of England, until eventually it overflowed bodily and crept southward across the midland table-land on its way to the valley of the Severn and the Bristol Channel. This remarkable glacial invasion is proved not only by the carry of local stones, and stones which have come south from the northern counties and Scotland, but by the appearance in the till at Cornelian Bay and Holderness of bowlders of two well-known Norwegian rocks, which were recognized by Mr. Amund Helland. . . .

The ice which would thus appear to have streamed transversely across England eventually coalesced with that which overflowed from the basin of the Irish Sea southeast through Cheshire, together with that which streamed east from the Welsh uplands, and the united *mer de glace* thereafter made its way into the Bristol Channel. Here it joined the thick ice that flowed out to sea from the high grounds of South Wales, the bottom-moraine of which is conspicuous not only in the mountain-valleys of that region, but also upon the low-

lying tracts that extend from the hills to the sea. In the southeastern counties, so far as we know at present, the ice-sheet at the climax of the Glacial period did not extend farther than the valley of the Thames, beyond which no trace of its bottom-moraine has been met with.*

Professor A. Geikie summarizes the facts concerning the continent as follows:

In Scandinavia the ice-striæ run westward and southwestward on the Norwegian coasts, and eastward or southeastward across the lower grounds of Sweden. When the ice descended into the basin of the Baltic and the plains of northern Germany, it moved southward and southwestward, but seems to have slightly changed its direction in different areas and at different times. Its movements can be made out partly from the striæ on the solid rock, but more generally from the glacial drift which it has left behind. Thus it can be shown to have moved down the Baltic into the North Sea. At Berlin its movement must have been from east to west. But at Leipsic, as recently ascertained by Credner, it came from north-northwest to south-southeast, being doubtless shed off in that direction by the high grounds of the Harz Mountains. Its southern limit can be traced with tolerable clearness from Jevennaar, in Holland, eastward across the Rhine Valley, along the base of the Westphalian hills, round the projecting promontory of the Harz, and then southward through Saxony to the roots of the Erzgebirge. Passing next southeastward along the flanks of the Riesen and Sudeten chain, it sweeps across Poland into Russia, circling round by Kiev, and northward by Nijni-Novgorod toward the Urals. It has been estimated that, excluding Finland, Scandinavia, and the British Isles, the ice must have covered no less than 1,700,000 square kilometres of the present lowlands of Europe. . . .

The ice is computed to have been at least between 6,000 and 7,000 feet thick in Norway, measured from the present sea-level. From the height at which its transported *débris* has been observed on the Harz, it is believed to have been at

* "Prehistoric Europe," pp. 189, 190, 192, 193.

least 1,470 feet thick there, and to have gradually risen in elevation as one vast plateau, like that which at the present time covers the interior of Greenland. Among the Alps it attained almost incredible dimensions. The present snow-fields and glaciers of these mountains, large though they are, form no more than the mere shrunken remnants of the great mantle of snow and ice which then overspread Switzerland. In the Bernese Oberland, for example, the valleys were filled to the brim with ice, which, moving northward, crossed the great plain, and actually overrode a part of the Jura Mountains, for huge fragments of granite and other rocks from the central chain of the Alps are found high on the slopes of that range of heights.*

More recently the late Professor H. Carvill Lewis studied the field in Great Britain, and published conclusions somewhat different from those which had been before accepted. He traced, according to the summary given by Upham, a terminal moraine "across southern Ireland from Tralee on the west to the Wicklow Mountains and Bray Head southeast of Dublin; through the western, southern, and southeastern portions of Wales; northward by Manchester, and along the Pennine Chain to the southeast edge of Westmoreland, thence southeast to York, and again northward to the Tees, and thence southeastward along the high coast of the North Sea to Flamborough Head and the mouth of the Humber." †

Professor Lewis propounded the theory that the supposed glacial deposits in England south of this line of terminal moraine were to be explained as water-deposits in a glacial lake produced by the damming up of the Humber River and a slight elevation of the earth at the Straits of Dover. It is proper to say, also, that in this theory Professor Lewis had been in part anticipated by Professor Boyd Dawkins, who had written as follows:

The ice at this time was sufficiently thick to override Schihallion, in Perthshire, at a height of 3,500 feet, and the

* "Text-Book of Geology," pp. 885, 886.

† "The American Geologist," vol. ii, 1888, p. 375.

hills of Galway and Mayo at 2,000 feet. Its southern limit in Britain is uncertain. According to Professor Ramsay and Dr. James Geikie, it extended as far south as the latitude of London, but the hypothesis upon which this southern extension is founded—that the bowlder-clays have been formed by ice melting on the land—is open to the objection that no similar clays have been proved to have been so formed, either in the arctic regions, where the ice-sheet has retreated, or in the districts forsaken by the glaciers in the Alps or Pyrenees, or in any other mountain-chain. Similar deposits, however, have been met with in Davis Strait and in the North Atlantic, which have been formed by melting icebergs; and we may, therefore, conclude that the bowlder-clays have had a like origin. . . . The English bowlder-clays, as a whole, differ from the *moraine profonde* in their softness and the large area which they cover. Strata of bowlder-clay at all comparable to the great clay mantle covering the lower grounds of Britain north of the Thames are conspicuous by their absence from the glaciated regions of central Europe and the Pyrenees, which were not depressed beneath the sea.*

Professor Lewis's views are of such interest that our treatment of the subject would be incomplete without a fair presentation of them, which can best be done in his own words:

The great ice-sheet which once covered northern England was found to be composed of a number of glaciers, each of which was bounded by its own lateral and terminal moraines. These glaciers were studied in detail, beginning with the east of England; and the North Sea Glacier, the Wensleydale Glacier, the Stainmoor Glacier, the Aire Glacier, the Irish Sea Glacier, and the separate Welsh glaciers were each found to be distinguished by characteristic bowlders, and to be defined by well-marked moraines. The terminal moraine of the North Sea Glacier, filled with Norwegian bowlders, may be seen in Holderness, extending from the mouth of the Humber to Flamborough Head, and consists of a series of conical hills inclosing meres. The moraine of the Stainmoor Glacier, char-

* "Early Man in Britain," pp. 116, 117.

acterized by blocks of Shap granite, may be followed northward along the coast past Scarborough and Whitby; then west along the Cleveland Hills; then south again through Oulston to the city of York; then west to near Allerton, where the Stainmoor Glacier is joined by the Wensleydale Glacier, a fine medial moraine marking the line of junction. The Wensleydale Glacier is characterized by bowlders of carboniferous limestone and sandstone, and its lateral moraine is followed northward through Wormald Green, Markington, Fountains Abbey, and along the Permian outcrop to Masham, where it turns west to Wensleydale, passing Jervaulx Abbey, and running up the valley. North of Wensleydale the moraine of the Stainmoor Glacier is followed through Richmond to Kirby Ravensworth, and westward to the mountains, where the glacier attained an elevation of two thousand feet. Thus the Stainmoor Glacier, a tongue of the great Irish Sea Glacier, had been divided into two branches by the Cleveland Hills, one branch going south to the city of York, which is built on its terminal moraine, the other branch flowing out of the Tees, and being deflected southward along the coast by the North Sea Glacier, with which it became confluent.

The Irish Sea Glacier, the most important glacier of England, came down from Scotland, and being re-enforced by local ice-streams, and flowing southward until it abutted against the mountains of Wales, it was divided into two tongues, one of which flowed to Wellington and Shrewsbury, while the other went southwest across Anglesey into the Irish Sea. This great glacier and its branches are all outlined by terminal moraines. A small tongue from it, the Aire Glacier, was forced eastward at Skipton and has its own distinctive moraine. In the neighborhood of Manchester the great moraine of this Irish Sea Glacier may be followed through Bacup, Hey, Stalybridge, Stockport, and Macclesfield, being as finely developed as the moraines of Switzerland and America. South of Manchester, it contains flint and shell fragments, brought by the glacier from the sea-bottom over which it passed. At Manchester the ice was at least fourteen hundred feet thick, being as thick as the Rhône Glacier.*

* Abstract by the author of a paper read at the Birmingham meeting of the British Association, September, 1886.

In a paper before the British Association in September, 1887, Professor Lewis presented his views in greater detail, and answered objections, alleging that—

The hypothesis of extra-morainic fresh-water lakes, dammed up by the glaciers, is sustained by all observed facts. The most important of these lakes was one caused by the obstruction of the mouth of the Humber by the North Sea Glacier, whose terminal moraine crosses that river at its mouth. This large lake reached up to the 400-foot contour line, and extended southward nearly to London, and westward in finger-like projections into the many valleys of the Pennine Chain. It deposited the "great chalky bowlder-clay," and erratics were floated in all directions by icebergs. It was bounded in the vale of York by the Stainmoor Glacier, and Charnwood Forest was an island in it. At its flood period it overflowed southwestward by torrential streams into the Severn Valley and elsewhere, carrying the "Northern Drift" into the south of England. Other glaciers in England were bordered by similar but smaller lakes wherever they advanced against the drainage. Three such lakes were made by the Aire Glacier, the largest of them extending to Bradford. The Irish Sea Glacier caused many similar lakes high up on the west side of the Pennine Chain, and at its southern end north of Wolverhampton. The overflow streams from the most southern of these lakes joined those issuing from Lake Humber in the Birmingham district, characterized by a "commingling of the drift," otherwise inexplicable. An examination of the supposed evidences for glaciation, and for a great marine submergence in central and southern England, shows that neither theory is sustained by the facts. Thus, the supposed striæ on Rowley Rag prove to be root-marks or plow-marks; those reported at Charnwood Forest to be due to running water, or perhaps icebergs; the supposed drift on the chalk-wolds to be a local wash of chalk-flints; the high-level gravels on the Cotteswold Hills to be preglacial; the shells at Macclesfield, Moel Tryfan, and Three Rock Mountain to be glacier-borne, and not a proof of submergence; the drift on the Pennine plateau of north Derbyshire to be partly made by icebergs floating in Lake

Humber, and partly a decomposed millstone grit or Bunter sandstone; and the supposed Welsh erratics on Frankley Hill at a height of eight hundred feet to be in place and due to an outcrop of the palæozoic floor.

The conclusion that the glacial phenomena of England are due neither to a universal ice-cap nor to a marine submergence, but to a number of glaciers bordered by temporary fresh-water lakes, is in accordance with all the observations of the author in England and elsewhere.*

It is fair to add, however, that soon after this meeting of the British Association at which this paper was read, his observations at Frankley Hill, in Worcestershire, and westward, led Professor Lewis to waver in his views, and he had resolved to go over all the ground again; but his untimely death prevented the accomplishment of this plan. Probably there can be little doubt of the correctness of Mr. Upham's conclusion that, if Lewis had lived, he would have accepted the opinions of the majority of the geologists of Great Britain, that land-ice really extended at one time as far south as the Thames. "Still, small portions of northern England escaped glaciation; . . . and these tracts of the high moorlands in eastern Yorkshire and of the eastern flank of the Pennine Chain are similar to the driftless area of southwestern Wisconsin." It would seem from Professor Lewis's facts about a moraine in England, as well as from those presently to be stated concerning Professor Salisbury's discoveries in northern Germany, that the farthest extent of the ice-front is, in Europe as well as in America, considerably in advance of the well-defined terminal moraine, and suggests the same difference of interpretation as here—i. e., this moraine is either the remnant of a later glacial period or it is a moraine of retrocession.

* See also "American Journal of Science," vol. cxxxii, 1886, pp. 433–438; "Proceedings of the Boston Society of Natural History," 1887; "Ueber Glacialerscheinungen bei Gommern unweit Magdeburg" ("Zeitschr. d. Deutschen geolog. Gesellschaft, Jahrg., 1883," pp. 831–848), and "Mittheilungen ueber das Quartaer am Nordrande des Harzes" (ibid., "Jahrg., 1885," pp. 897–905), von F. Wahnschaffe, in Berlin.

The conclusion of Professor Lewis concerning the marine shells found at high elevations in glacial deposits on the mountains of Wales, and which have generally been taken to indicate a deep submergence during the Glacial epoch or at the beginning of the second Glacial epoch, are of the greatest importance, and coincide with similar discoveries recently announced by Mr. Upham concerning the shells found in the vicinity of Boston, and supposed to indicate a post-glacial subsidence of considerable extent in that vicinity. These shells in the British Isles, like those in the vicinity of Boston, are mostly in fragments, are very thick and compact in structure, and often water-worn and sometimes striated. Their elevation in the British Isles reaches as much as thirteen hundred and fifty feet above tide. Professor Lewis thinks they were plowed up by the glacier as it passed over the trough of the Irish Sea, and were elevated to their present position by the ice in the same manner that bowlders are seen so often to have been elevated in various parts of the United States. I again adopt the words of Mr. Upham in his recent comments upon this theory:

The ample descriptions of the shelly drift of these and other localities of high levels, and of the lowlands of Cheshire and Lancashire, recorded by English geologists, agree perfectly with the explanation given by Lewis, which indeed had been before suggested, so long ago as 1874, by Belt and Goodchild. This removes one of the most perplexing questions which glacialists have encountered, for nowhere else in the British Isles is there proof of any such submergence during or since the Glacial period, the maximum known being five hundred and ten feet near Airdrie, in Lanarkshire, Scotland. At the same time the submergence on the southern coast of England was only from ten to sixty feet, while no traces of raised beaches or of Pleistocene marine formations above the present sea-level are found in the Orkney and Shetland Islands.*

* "American Geologist," vol. ii, p. 375.

The work begun by Professor Lewis was subsequently carried on by The Northwest of England Bowlder Committee, of which Professor Percy F. Kendall was for some years the efficient chairman. The final conclusion from these and other investigations are thus briefly summarized by Dr. F. W. Harmer,* as follows:

"Most glaciologists believe that this country was invaded by ice, on the east from the German Ocean, and on the west from the Irish Sea. Crossing the Lincolnshire Wolds, ice from the North Sea, augmented, I think, by that of an inland glacier from the Vale of York, traveled towards the plain of the lower Witham and the Fenland, whence it overspread a large tract of country to the east, the south and the west. To the east it reached the Suffolk coast, to the south nearly to the valley of the Thames, while to the west it filled those of the Welland, the Nene, and the Ouse, overriding also the highland intervening.

"Another branch of the northern glacier, keeping to the west of the Lincoln ridge, and reinforced by the North-Sea ice, moved towards Doncaster and up the Trent basin to the vicinity of Derbe, where it met the Derwent glacier, and thence crept southward along the valley of the Soar into Warwickshire.

"On the west, the Cheshire plain was invaded by ice from the Irish Sea which, diverting the glaciers descending from the mountains of North Wales towards the south, carried vast numbers of Scottish and Lake-District erratics into the northern part of the basin of the Lower Severn, heaping them also upon Cannock Chase, and upon the high land near Wolverhampton.

"In South Wales, Dr. Strahan and his colleagues have shown that ice descended in great thickness from the Brecknock Beacons towards the Bristol Channel, reaching the shores of the latter near Swansea, filling the Neath and Taff valleys to overflowing, and rising to a great height on the intervening hills.

*"Quarterly Journal of the Geological Society" for November 1907, vol. lxiii, p. 471-474.

"Evidence has also been found of the invasion of the southern part of this district by ice from the Irish Sea, which is supposed to have traveled up the Bristol Channel from west to east, and to have crossed the Pembrokeshire peninsula from St. David's Head towards Gower and to the neighborhood of Cardiff: erratics believed to have been derived from the first-named locality have been found nearly 100 miles to the eastward of their probable source.

"The depth of St. George's Channel between St. David's Head and Ireland, however, exceeds 50 fathoms, and the natural course of the Irish-Sea glacier, joined by those descending the western slopes of the Welsh mountains, should have been southward along the great submarine valley opening out to the Atlantic. The distribution of the erratics just mentioned seems therefore to indicate that the volume of ice, approaching the narrowest part of St. George's Channel, was too great to enable it wholly to escape in that direction, some of it being forced by lateral pressure to travel eastward up the Bristol Channel.

"It seems worth considering whether so important an ice-stream would not have blocked the entrance to the estuary of the Severn, the result being an accumulation of sedentary ice in the valley of that river, derived partly from the glaciers of central Wales and partly from Atlantic blizzards, which may have prevailed at that epoch.

"This view may possibly throw light on the origin of the great alluvial and lake-like plain of Glastonbury, and of the gorge at Clifton . . . It may explain also why Arenig boulders have been piled up on the Clent Hills, southwest of Birmingham, to a height of nearly 900 feet. It is difficult to understand that this could have occurred, if at that time the Welsh ice could have followed an unobstructed course along low ground towards the Bristol Channel.

"The conditions here sketched out, namely, of ice moving upon central England from the sea in a direction opposed to that of the natural drainage, are precisely those under which glacial lakes with their accompanying over-flow channels would have naturally originated."

During the summer of 1888 Professor Salisbury, who had been for several years associated with President Chamberlin in the glacial survey of the Northwestern States and Territories, made also a hasty survey of northern Germany for the purpose of correlating the glacial deposits of that country with those in America. The results were most important and interesting.* He found a double series of terminal moraines back some distance from the extreme glaciated limits, as in the Northwestern States of America, and resembling them both in their composition and in their situation with reference to the marginal deposits. As traced by Professor Salisbury, this belt of moraines follows approximately the curve of the south shore of the Baltic Sea, and not many miles from it. Its course lies through Schleswig-Holstein, Mecklenburg, Potsdam (about forty miles north of Berlin), thence swinging more to the north, and following nearly the line between Pomerania and West Prussia, crossing the Vistula about twenty miles south of Dantzic, thence easterly to the Spirding See, near the boundary of Poland.

Among the places where this moraine can be best seen are—"1. In Province Holstein, the region about (especially north of) Eutin; 2. Province Mecklenburg, north of Crivitz, and between Bütow and Kröpelin; 3. Province Brandenburg, south of Reckatel, between Strassen and Bärenbusch, south of Fürstenberg and north of Everswalde, and between Pyritz and Solden; 4. Province Posen, east of Locknitz, and at numerous points to the south, and especially about Falkenburg, and between Lompelburg and Bärwalde. This is one of the best localities. 5. Province West Preussen, east of Bütow; 6. Province Ost Preussen, between Horn and Widikin."

Comparing these with the moraines of America, Professor Salisbury remarks:

In its composition from several members, in its variety of development, in its topographic relations, in its topography, in

* Professor R. D. Salisbury on "Terminal Moraines in Northern Germany," in "American Journal of Science," vol. cxxxv, 1888, pp. 405, 406.

FIG. 123.—Map showing the glaciated area of Europe according to J. Geikie, and the moraines in Britain and Germany according to Lewis and Salisbury.

its constitution, in its associated deposits, and in its wide separation from the outermost drift limit, this morainic belt corresponds to the extensive morainic belt of America, which extends from Dakota to the Atlantic Ocean. That the one formation corresponds to the other does not admit of doubt. In all essential characteristics they are identical in character. What may be their relations in time remains to be determined.

FIG. 124—Contorted drift of the Cromer ridge; the terminal moraine of the North Sea ice.

The glaciated areas of the Pyrenees and the Alps are independent of that covered by Scandanavian ice. In France, small glaciers were to be found in the higher portions of the Auvergne, of the Morvan, of the Vosges, and of the Cevennes; while from the Pryenees, glaciers extended northward throughout nearly their whole extent. The ice-stream descending from the central mass of Mt. Maladetta through the upper valley of the Garonne, was joined by several tributaries, and attained a length of about forty-five miles.

The Alpine glaciers were much more extensive, filling the whole valley between them and the Jura Mountains, and pushing up upon them to their summits. Eastward they deployed in the valley of the Rhine as far as Strassburg, and westward into the valley of the Rhone as far as Lyons, while southward they extended nearly to Turin and Verona in the valley of the Po. The accompanying map of Professor Penck shows their full extension eastward into Austria and the three successive epochs which he names the Würm, the Riss, and the Mindel, after the three rivers in which the several deposits were most typically preserved. These correspond to the Wisconsin, the Illinoisan and the Kansan episodes in America, and were readily recognized as such by Mr. Leverett. For its bearing on later theorizing, it is worthy of notice that these several borders are closely parallel to each other and not separated by any great distance.

FIG. 124a.—Present and past glaciation of the Alps. (Map by Leverett)

CHAPTER XIX.

THE CAUSE OF THE GLACIAL PERIOD.

For the past few years speculation concerning the cause of the Glacial period has been largely dominated by an astronomical theory. But geologists have in general felt the impropriety, in such an important matter, of abandoning their own field to accept the glittering results of celestial mathematics. At any rate, it would be improper for them to let the astronomical solution go unchallenged. If the geologist suffers himself to be lifted into the air, like the fabled Antæus, he labors at a disadvantage, and can be easily overcome. For this reason the glacialists of America have, of late, limited their labors chiefly to the collection of terrestrial facts, and when asked, as they often are, "What was the cause of the Glacial period?" the first answer has frequently been, "That is none of our business." Still, it is by the interpretation of facts that causes are discovered, and the collection of facts concerning the glaciation of North America has advanced so rapidly during the past few years, that it is now high time to consider more fully their meaning and discuss the subject anew, if for no other reason than for the sake of finding out how little is known about it.

It is easily seen that a glacier is the combined product of cold and moisture. A simple lowering of the temperature will not produce an ice age. Before an area can maintain a glacier, it must first get the clouds to drop down a sufficient amount of snow upon it. A climate which is cold and dry may not be so favorable to the production of glaciers as one which is temperate, but whose climatic conditions are such

that there is a large snow-fall. For example, on the steppes of Asia, and over the Rocky Mountain plateau of our Western States and Territories, the average temperature is low enough to permit the formation of extensive glaciers, but the snow-fall is so light that even the short summers in high latitudes cause it all to disappear; whereas, on the southwestern coast of South America, and in southeastern Alaska, where the temperature is moderate, but the snow-fall is large, great glaciers push down to the sea even in low latitudes.

The circumstances, then, pre-eminently favoring the production of glaciers, are abundance of moisture in the atmosphere, and climatic conditions favorable to the precipitation of this moisture as snow rather than as rain. Heavy rains produce floods, which speedily transport the water to the ocean-level; but heavy snows lock up, as it were, the capital upon dry land, where, like all other capital, it becomes conservative, and resists with great tenacity both the action of gravity and of heat. Under the action of gravity glaciers move, indeed, but they move very slowly. Under the influence of heat ice melts, but in melting it consumes an enormous amount of force.

In order to melt one cubic foot of ice, as much heat is required as would heat a cubic foot of water from the freezing-point to 176° Fahr., or two cubic feet to 88° Fahr. To melt a layer of ice a foot thick will therefore use up as much heat as would raise a layer of water two feet thick to the temperature of 88° Fahr.; and the effect becomes still more easily understood if we estimate it as applied to air, for to melt a layer of ice only one and a half inch thick would require as much heat as would raise a stratum of air eight hundred feet thick from the freezing-point to the tropical heat of 88° Fahr. We thus obtain a good idea, both of the wonderful power of snow and ice in keeping down temperature, and also the reason why it takes so long a time to melt away, and is able to go on accumulating to such an extent as to become permanent. These properties would, however, be of no avail if it were liquid, like water; hence it is the state of solidity and almost complete

immobility of ice that enables it to produce by its accumulation such extraordinary effects in physical geography and in climate as we see in the glaciers of Switzerland, and the ice-capped interior of Greenland.*

Theories respecting the causes of the glacial period altogether number more than half a score, principal of which are the following: 1. A decrease in the original heat of the planet; 2. The shifting of the polar axis; 3. A former period of greater moisture in the atmosphere; 4. The depletion of carbon dioxide in the atmosphere by chemical union and oceanic absorption; 5. Variations in the temperature of space; 6. Variations in the amount of heat radiated by the sun; 7. The combined effect of the precession of the equinoxes and of the changing eccentricity of the earth's orbit; 8. Changes in the distribution of land and water; 9. Elevation of the lands in northern Europe and America to a higher level than that now occupied.

Though these causes cannot in all cases, and perhaps not in any case, be supposed to act except in combination with one another, it will be profitable to consider them separately.

If, according to the first theory, the Glacial period was due to a decrease of the original heat of the planet, the period should not have culminated in the past, but we should still be looking for its culmination in the future; for both the earth and the sun are cooling off. We may, therefore, drop out the first theory.

If, according to the second theory, the cause had been the shifting of the earth's axis of rotation, we should not find, as we now do, evidences that the warm climate which preceded the Glacial period approached the poles along the present circles of latitude; but, as it is, we find that the temperate flora which covered the arctic regions at the close of the Tertiary period approached the pole not only in Greenland and British America, but also in Spitzbergen and Nova

* Wallace's "Island Life," pp. 127, 128.

Zembla. We may, therefore, drop this second theory out of consideration.

The third theory, so ably advocated by Professor Whitney, that the Ice age was the direct result of the excessive moisture of earlier periods, and that the disappearance of glaciers is to be accounted for by a general drying up of the earth, is ruled out by the fact that there is evidence, among other things, from the vast deposits of salt existing in numerous parts of the world, that the work of desiccation has been going on in some portions of the earth from the earliest geological ages. For example, central New York is, at the present time, one of the best-watered portions of the world; but it is underlaid by deposits of salt sixty or seventy feet in thickness, and these extend under much of the area of Upper Canada and Michigan. To produce this amount of salt there must have occurred, during the Upper Silurian age, the drying up of an inland sea over that region a mile in depth. We are compelled, therefore, to regard the era of the saline group of rocks, rather than the present, as the great age of desiccation. Besides, moisture in the atmosphere is efficient as a glacial cause only when it is precipitated as snow, and this must be determined by general meteorological conditions. There is probably moisture enough always in the air to produce an ice age if the conditions can be combined to precipitate it in the right form and at the right place to encourage the growth of glaciers.

The fourth theory is that argued at great length by Professors Chamberlin and Salisbury ("Geology," vol. ii, 665, vol. iii, 432). According to this theory the presence of an excessive amount of carbon dioxide in the atmosphere increases the warmth of the earth's surface by reducing the radiation. Therefore, whatever reduces the carbon dioxide in the enveloping atmosphere of the earth will reduce its superficial temperature. It is well known that preceding the glacial epochs of the permian and pliocene periods there was a great extension of land areas on both continents accompanied by the formation of great mountain systems. This greatly in-

creased the absorption of carbonic dioxide from the atmosphere, through the growth of vegetable and animal life. This is shown by the coal and lignite deposits, and by the vast beds of limestone and other carbonates. Through this means it is suggested, the temperature of the whole earth was so lowered that glaciers began to form in the higher latitudes and on the higher mountains. Coincident with this general lowering of temperature the water of the ocean, especially in the higher latitudes, would begin to absorb a greater proportion of the carbon dioxide and carry it down.

The theory in full is much more complicated than this, and loses its value largely from this fact. But the most obvious objection to it is that the operation of the forces involved must be so slow that it could not fit into the rapid succession of events which crowded in upon one another during the last glacial period, which was characterized by numerous episodes of advance and recession of the ice-sheet and all within a very limited period even as geologists reckon time.

The fifth theory and the sixth naturally go together. That there may be variations in the temperature of space is entirely within the realm of possibility, and that the sun may be a variable star is a statement which can not be proved absolutely false. Indeed, the hypothesis that the heat of the sun is kept up by a bombardment of meteoroids is defended by eminent astronomers. In case this were true, a known natural cause for the production of variability is certainly in the field, since the cometary bodies, which are circulating irregularly through space, are probably themselves but ganglia of meteoroids which may readily get entangled within the predominant sphere of the sun's attraction, and become a means of increasing for a long period the amount of the sun's heat. This theory can not be positively affirmed to be true; but, as long as it can not be disproved by astronomical considerations, it remains in the field to diminish the confidence with which we support other hypotheses.

The seventh theory mentioned had in Mr. Croll and in Mr. James Geikie most able and convincing advocates, and for many years was generally accepted as sufficient and satisfactory. Briefly stated, the theory is this:

As is well known, the earth's orbit is not a circle, but an ellipse, whose longer diameter at the present time exceeds its shorter by about 3,000,000 miles. The sun is not in the center, but is in one of the foci of the ellipse, which at the present is about 1,500,000 miles outside of the center. As matters are now situated, therefore, the earth on the 21st of June (when it is said to be in aphelion) is 3,000,000 miles farther from the sun than it is on the 21st of December (when it is said to be in perihelion); that is, during the present winters of the northern hemisphere we are 3,000,000 miles nearer the sun than we are during the summers.

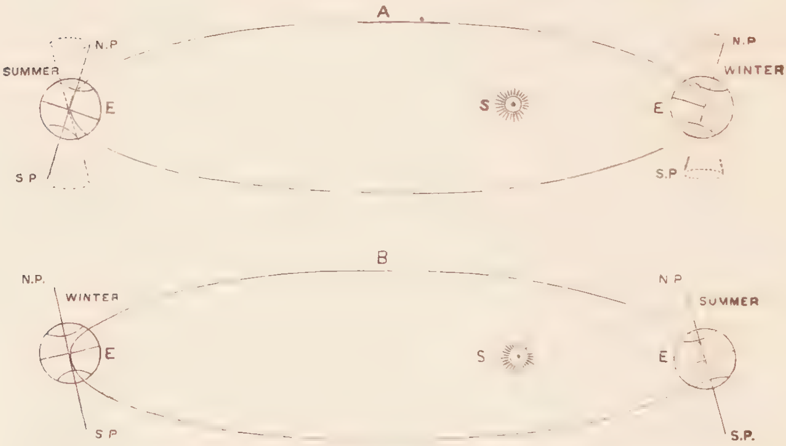

FIG. 125.—Exaggerated view of the earth's orbit, showing the effects of precession of the equinoxes. A, condition of things now; B, as it will be 10,500 years from now.

But, if a line be drawn through the earth's orbit joining the equinoxes—that is, the points passed through on the 20th of March and the 22d of September—we shall find that the winter is shorter than the summer. The period from the 20th of March to the 22d of September, which constitutes the summer, is one hundred and eighty-six days, while that

from September 22d to March 20th is only one hundred and seventy-nine days, or seven days less. So that, while the earth is farther away from the sun during the summer, and receiving daily less heat, the additional seven days occupied by that part of the journey makes ample compensation, and the absolute amount of heat received during the longer time exactly equals that received by the earth during the shorter half of its journey. It will be observed, also, that when the summer in the northern hemisphere occurs at aphelion, the summer in the southern hemisphere occurs in perihelion, thus exactly reversing the conditions.

Now it is claimed by Mr. Croll and others that when, in either hemisphere, the winter is short and occurs in perihelion, the climate of that hemisphere will be less favorable to the production of glaciers than in the hemisphere where the winter is long and in aphelion. Consequently, according to their theory, the situation of the earth is now favorable to the production of glaciers in the southern hemisphere, and unfavorable to their production in the northern. This theory is not based, however, on the idea that the hemisphere whose winter is in aphelion receives less heat from the sun than the other hemisphere during that season, but upon the supposition that the greater period occupied by the sun in passing through aphelion when the winter nights are long, gives more opportunity for the loss of heat during winter in that hemisphere by radiation.

Now, if it be correct that a winter in aphelion is favorable to glaciation, and a winter in perihelion unfavorable, then, from the astronomical changes which transfer this condition periodically from one hemisphere to another, we can reason that the northern and southern hemispheres are alternately subjected to conditions favorable to glaciation. For, through what is called the "precession of the equinoxes," the periods of aphelion and perihelion are exactly reversed in their relations to the two hemispheres every 10,500 years. The points at which the equinoxes occur are slowly slipping around, making a revolution once in about 21,000 years; so that,

10,500 years from the present time, the winter in the northern hemisphere will occur in aphelion instead of perihelion; and, if the supposition be correct concerning the influence of this increased length of the winter and distance of the earth from the sun, the conditions would favor the return of a glacial period 10,000 or 11,000 years hence, and would imply that similar favorable conditions existed 10,000 or 11,000 years ago. According to this theory, also, there should have been a succession of glacial periods every 21,000 years during long ages past.

But there is still another periodicity in the movements of the earth about the sun with which to combine the preceding. The shape of the earth's orbit is not permanent, but through the influence of the attraction of the planets upon it is subject to periodic changes. In astronomical terms, the "eccentricity" of the earth's orbit is subject to variations; that is, there are sometimes very much greater differences than at present between the longer and the shorter diameters of the earth's orbit. When this difference is greatest it amounts to no less than 7,000,000 miles; so that at certain times the earth is 14,000,000 miles farther from the sun in winter than in summer, and *vice versa*. At the time of greatest eccentricity, also, the difference in length between the summers and winters would amount to thirty-six days, instead of seven or eight as now.

These periods of greatest eccentricity in the earth's orbit during which, on Mr. Croll's theory, the conditions were extremely favorable for the production of glacial epochs, are somewhat unevenly distributed. One of them culminated 200,000 years ago; another, 750,000; another, 850,000; another, 2,500,000; and another, 2,600,000. In the future they will occur 500,000, 800,000, 900,000 hence. In the present condition of the earth's orbit this supposed cause is at its minimum.

Of the astronomical changes affecting the eccentricity of the earth's orbit, we are certain. But the value of Croll's theory depends upon the correctness of the original assump-

tion, that when the winters occur in aphelion there will be a great increase of snow-fall and a marked lowering of temperature during the winter; and that, during the summers, heat would have less than its average influence in removing the snows of the previous winter. As already remarked, however, it should be noted that Mr. Croll's calculations upon these two points do not rest upon any difference in the estimate of the absolute amount of heat received during these periods. But he assumes that an excessive amount of heat would be lost from the earth by radiation during the long winters in aphelion; so that the effect from that cause, when accumulated during a number of centuries, would be marked by a noticeable increase in the glacial fields of the hemisphere whose winter was in aphelion, and this would be connected with the decrease of glaciers in the other hemisphere, whose winters were correspondingly short and in perihelion.

Having got glaciation started in one hemisphere during periods when the winters were in aphelion, Mr. Croll adduces an additional cause to help on the refrigeration, in the effect which this cause itself would have upon the winds and the ocean-currents. He estimates that the heat conveyed by the Gulf Stream into the Atlantic Ocean is equal to one fifth of all the heat possessed by the waters of the North Atlantic; or to the heat received from the sun upon a million and a half square miles at the equator, or two million square miles in the temperate zone. "The stoppage of the Gulf Stream would deprive the Atlantic of 77,479,650,000,000,000,000 foot-pounds of energy in the form of heat per day." The cause of the Gulf Stream, therefore, becomes a most important element in the problem. What is the force driving onward this immense body of warm water, which he estimates "to be equal to that of a stream fifty miles broad, a thousand feet deep, flowing at the rate of four miles an hour," and whose temperature as it emerges from the Straits of Florida averages as high as 65° Fahr., twenty-five degrees of which is eventually parted with to ameliorate the climate of the North Atlantic?

With great cogency of reasoning, Mr. Croll shows that the trade-winds are the predominant cause of the present course of the Gulf Stream. After attempting to show the failure of all other theories to account for ocean-currents, and for the direction of the Gulf Stream in particular, Mr. Croll calls attention to the general correspondence between the direction of the winds and that of the great currents of the ocean, and shows how powerful this agency must be in giving motion to the surface of the water, and by constancy of action, finally, to the lower strata of water. Now, from some cause or other, at the present time the southeast trade-winds are considerably stronger than the northeast. As a result, the southeast trades sometimes extend as far as latitude 10° or 15° north of the equator; while the northeast trades rarely extend even as far south as the equator.* The geo-

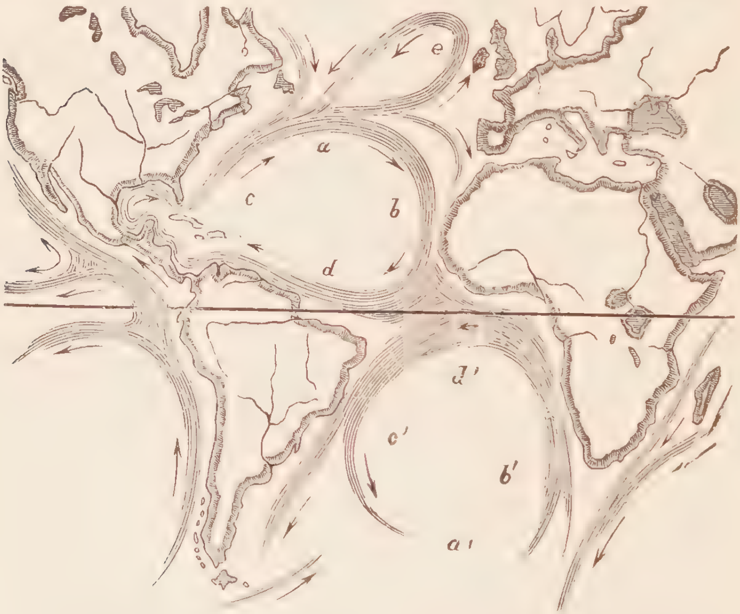

FIG. 126.—Map showing course of currents in the Atlantic Ocean. b and b' are currents set in motion by opposite trade winds; meeting they produce the equatorial current which divides into c and c' continuing on as a and a' and e

* Croll's "Climate and Time," p. 70.

FIG. 127.—July isobars and prevailing winds. The dotted lines inclose areas with pressure above thirty inches. The heavy lines inclose areas with pressure below thirty inches.

graphical position and contour of South America give special significance to this cause in its relation to the Gulf Stream and to all the regions dependent on it for warmth of climate.

Cape St. Roque, the easternmost point of South America, is only five degrees south of the equator, and is fifty degrees, or three thousand miles, east of the longitude of Florida. With the present relation of the trade-winds to each other, this situation of the continent of South America is favorable to the production of the Gulf Stream. For it is evident at a glance that the movement of water caused in the South Atlantic by the southeast trades will be at its maximum over the tropical belt in the vicinity of Cape St. Roque, and that the movement there will be in a general northwest direction. Hence there is great significance in the present contour of the continent, it being such that there is nothing to impede the movement of water once begun by the trade-winds in a northwest direction (at least, so much of it as is north of Cape St. Roque); but the current thus started must keep on its way until it reaches the *cul-de-sac* formed by the Gulf of Mexico, and from this there is no escape except through the passage between the West India Islands and Florida. Here we have a deep, strong current, produced by the same hydrostatic law which propels the comparatively small stream in the hydraulic ram. Or, to draw an illustration from a grander spectacle, the movement is like that of the tides when passing up through gradually restricted channels. In such cases the thin onward movement of the tidal wave over a wide space is translated into a narrow but deeper and more powerful current up the gradually restricted channel into which it is forced; so that, whereas the general height of the tidal wave is but two or three feet, it sometimes in restricted channels, like the Bay of Fundy, rises to the height of seventy feet, and the so-called "bore," characteristic of many tidal rivers, like the Orinoco and the Amazon, becomes the terror of navigators. Through such a translation of the gentle but steady pressure of the southeast trades over the wide area of the South Atlantic Ocean, the waters of the

Gulf Stream are projected through the Straits of Florida with a force sufficient to carry them across the Atlantic and to the shores of Iceland and Norway. So far Mr. Croll's explication is certainly very plausible, and seems to proceed from well-known physical principles, and is pretty generally accepted by scientific men.

This, however, is only the first step in his argument. Another glance at the map will show that if from any cause the relations of the trade-winds should be reversed, so that the northeast trades should predominate over the southeast, and extend some degrees south of the equator, then Cape St. Roque would intercept the movement caused by the southeast trades, and the warm water from the South Atlantic, which is now forced into the Caribbean Sea, would all of it do what part of it now does, namely, turn to the south, and, after following for a while the southwestern trend of the South American coast, would join the slow-moving whirlpool of the South Atlantic, whose center is on the parallel joining Montevideo and Cape Colony. It will thus appear that, in searching for the cause of the Gulf Stream, we are ultimately compelled to search for the cause of the present preponderance of the southeast trades in the Atlantic Ocean. This sends us backward upon a receding series of causes.

The southeast trades preponderate because the southern hemisphere is cooler than the northern hemisphere, for wind is but the movement of the cooler and therefore heavier atmosphere of one region toward a partial vacuum produced by a superior degree of heat in another. This conclusion pushes us back one step further to find the cause for the present lower relative temperature of the southern hemisphere, and here we strike what is probably a *coincidence*, but which Mr. Croll and his followers have too readily accepted as a cause. Mr. Croll thinks he finds the cause of the low temperature of the southern hemisphere in the present prevalence there, in moderate degree, of the astronomical conditions to which he has attributed the production of glacial periods. The winters of the southern hemisphere now

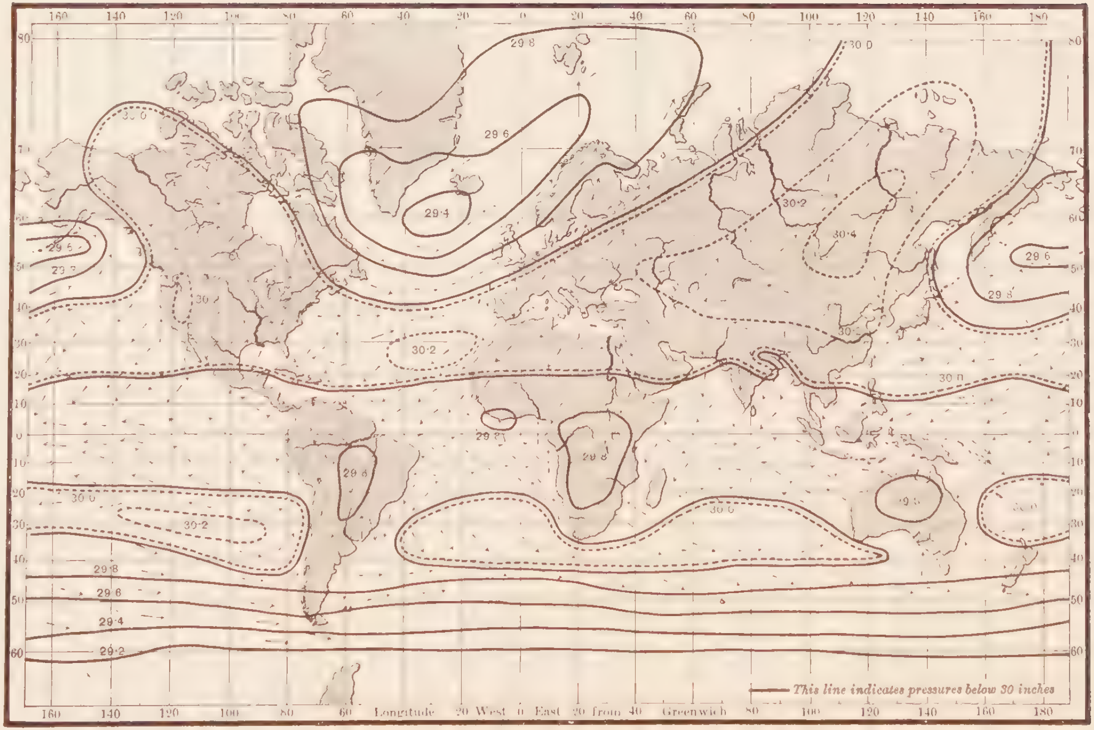

FIG. 128 January isobars. Dotted lines and heavy lines as before. Notice that even during the northern winter the northeastern trades only reach the equator, while in July the southeastern trades pushed up as far as 10° N.

occur in aphelion—that is, when the earth is farthest away from the sun, and are seven days longer than the summers. While admitting that there is not as yet enough known about the laws governing the absorption and retention of the sun's heat upon the earth's surface to permit us to say with confidence that the acknowledged glacial condition of the southern hemisphere is not produced by the astronomical cause under consideration, it must be added that we are also unable to prove the inadequacy of other causes to produce the same results. In assuming the reality of Mr. Croll's cause, we are in danger of resting on a theoretical *may be* rather than on well-established premises. At any rate, Woeikoff, in the ablest review that has yet appeared upon the subject, thinks the glaciation of the southern hemisphere may readily enough be accounted for without the aid of Croll's theory, and sums up the case thus:

The extent and depth of the oceans of the southern hemisphere give a greater steadiness and force to the winds of that hemisphere, and the difference is even more marked if we compare the westerly winds of middle latitudes rather than the trades, though also well seen in the latter. Now, land acts in two ways on the trade-winds: it weakens them, first, by the increase of friction. But this is not all. The trades, few ocean regions excepted, are not strong winds; they are important on account of their extent and steadiness. The gradient which causes them is small. Now, in such cases, land, even if it is not a continent but only a cluster of small islands, has a great influence on trade-winds in causing local gradients which may have even an opposite direction to the general gradients, thus causing different and even opposing winds. The land- and sea-breezes and the monsoons are cases in point. Even where the disturbances of the normal ocean gradients are not large enough to cause monsoons, we see generally the trades oftener interrupted in summer, when they are weaker and when local thunder-storms and rains are more frequent on land. For the two reasons given, the trades of the southern hemisphere must be more extensive and stronger than those of the northern.

The relatively small extent of sea in middle latitudes of the northern hemisphere, in comparison with the southern, must tend to warm the seas of the former, even if the quantity of warm water from the tropical seas reaching them be equal. Thus, generally in the middle latitudes the evaporation goes on at a higher temperature from the seas of the northern than the southern hemisphere. Now, this has a very great influence on the resulting precipitations; when the evaporation goes on at or near 32°, there is much more probability that the resulting precipitation will be snow and not rain, even on low lands; the higher the temperature at which the evaporation takes place, the greater must be the height at which snow can fall, on account of cooling by expansion.

Not all cold seas are favorable to glaciation. If they are surrounded by land on which the winters have a temperature considerably below 32°, they will be covered with ice, and thus evaporation will be checked just at the time when it is most favorable to snow-fall. The ice of the seas will be covered with snow, the temperature of the air over it may be very low, but the snow-fall will not be great, and thus the conditions not favorable to glaciation. Such is the condition of many seas of the northern hemisphere, as the Arctic Ocean north of Siberia, the Kara Sea, the bays and inlets north of the North American Continent, the Sea of Okhotsk, etc., which are covered with ice during many months. These conditions are favorable to cold of many months' duration, but not to a large snow-fall and the resulting glaciation. The observations made at many points off the coasts of Siberia and the North American Archipelago have shown that the snow-fall is exceedingly light. The seas between 45° and 70° of southern latitude are deep and not surrounded by land, and thus by far not so ice-bound, both on account of the absence of very low temperatures favorable to the formation of ice, and of the rupture of ice, when formed, by winds and currents.*

Thus it is shown that the depth and relative extent of the southern ocean furnish a sufficient cause for its present glacial conditions.

* "American Journal of Science," vol. cxxxi, 1886, pp. 175, 176.

As already intimated, the weak point in Mr. Croll's theory is the general state of uncertainty as to the laws regulating the absorption, retention, and distribution of the sun's heat upon the earth. It is evident that the heat upon which the earth is dependent is that of the sun; since, as Professor Newcomb has shown, the total amount of heat received from the stars is probably not one-millionth part of that received from the sun.* Now, as all admit that the *annual* amount of heat received from the sun is not affected by changes either in the eccentricity of the earth's orbit, or in the relation of the poles to that eccentricity, it is only the question of the retention and distribution of heat with which we have to do. And here we come to a most obscure realm of scientific investigation, where ignorance is still profound. The reason why the summit of a mountain is cold is not because of lack of heat from the sun, but it arises rather from the facility with which the heat is dissipated by radiation. On the contrary, the reason why the atmosphere of a greenhouse is warmer than that upon the outside is not because it *receives* more heat, but because it *retains* more. The intenser heat-rays of the sun readily penetrate the glass cover, while the less intense rays of radiated heat from the earth are unable to do so in return. It is well known, also, that clouds prevent a frost by checking the radiation from the surface of the earth. The laws regulating the influence of the atmosphere and the floating particles contained in it, over the retention of the sun's heat in its lower strata, are as yet but little understood. There is here an almost unlimited field for investigation and discovery.

And this, as just remarked, is the weak point of Mr. Croll's theory. Everything here depends upon the forces which distribute the heat and moisture over the land-surfaces. It is by no means certain that, when the winters of the northern hemisphere occur in aphelion, they will be colder than now. Whether they would be so or not depends

* "American Journal of Science," vol. cxi, 1876, p. 264; vol. cxxvii, 1884, p. 22.

upon the action of forces whose laws can not now be accurately calculated. As Woeikoff goes on to show, there are some very singular facts in the distribution of heat over the earth's surface—proving that the equator is not so hot as theoretically it ought to be, and that the arctic regions are not so cold; and this in places which could not be affected by oceanic currents. For example, at Iquitos, on the Amazon, only three hundred feet above tide, three degrees and a half south of the equator, and more than a thousand miles from the Atlantic (so that ocean-currents can not abstract the heat from its vicinity), the mean yearly temperature is but 78° Fahr., while at Verkhojansk, in northeast Siberia, which is 67° north of the equator, and is situated where it is out of the reach of ocean-currents, and where the conditions for the radiation of heat are most favorable, and where, indeed, the winter is the coldest on the globe (January averaging −56° Fahr.) the mean yearly temperature is two degrees and a half above zero; so that the difference between the temperature upon the equator and that at the coldest point on the sixty-seventh parallel is only about 75° Fahr.; whereas, if temperature were in proportion to heat received from the sun, the difference ought to be 172°. Again, the difference between the actual January temperature on the fiftieth parallel and that upon the sixtieth is but 20° Fahr., whereas, the quantity of solar heat received on the fiftieth parallel during the month of January is three times that received upon the sixtieth, and the difference in temperature ought to be about 170° Fahr. upon any known law in the case.

But to be quite sure to get beyond the influence of ocean-currents, I will take the mean January temperature in the strictly continental climate of eastern Siberia, under 120° east. According to Ferrel's tables:

Under 50° north we have 0° Fahr.
Under 60° north we have −30° Fahr.

If the January temperature decreased from 50° to 60° north, according to the hypothesis of Dr. Croll, it should be on the 60° north −155° Fahr.

But to be quite sure of taking the most favorable case for the hypothesis of Dr. Croll, I take the highest January temperature on the 50° north in Ferrel's tables, that is, that on 20° east = 44° Fahr., and the coldest January temperature on the 60° north, that is, that of 120° and 130° east, = −30° Fahr. Yet in proportion to the quantity of heat received, the mean temperature of January on 60° north should be −140° Fahr.

The following table gives the results of the three cases considered:

	Mean temperature 50° N.	MEAN TEMPERATURE, 60° N.		Difference
		On the hypothesis of Dr. Croll.	Actual.	
Mean January temperature of all meridians................	21·3	− 147·9	1·7	149·6
Mean January temperature in 120° E. (east Siberia)........	0°	− 155·3	−30	125·3
Mean January temperature of warmest meridian 50° N., and coldest meridian on 60° N....	44·0	− 140·0	−30	110·0*

These facts, and many others like them, make it evident that we understand very little about the laws governing the distribution of heat over the surface of the earth. Other things besides ocean-currents are active in the matter, and some of them must be far more potent than any cause which we now clearly discern. We quote again the words of the same high authority:

How can we judge of the change of temperature resulting from this or that distance from the sun, even if we knew accurately the temperature of space, when we do not know the diathermancy of the atmosphere under different conditions? We know only that it is exceedingly different, according to the different quantities of carbonic acid and aqueous vapor contained in it, and in a far higher degree, according to the absence or presence in different quantities of suspended liquid and solid particles (clouds, dust, smoke, etc.). Thus, when

* Woeikoff in "American Journal of Science," vol. cxxxi, p. 166.

we do not know in how far the loss of heat is impeded, even an accurate knowledge of the temperature of space would be of small use in this matter. I will illustrate this by a homely example. Take a room where the fire is extinguished and the hearth or stove cold in the evening, and try to guess at the temperature the room will have in the morning. If we follow the method of Dr. Croll, we should inquire only about the outside temperature, and not about the thickness of the walls, the windows, etc. I think that, taking the average construction of Russian, English, and Italian houses, if the inside temperature was in all three cases 60° in the evening, and the outside temperature 20° in Russia, 32° in England, and 45° in Italy, the morning temperature in the room would not be very different, and probably even higher in the Russian room, owing to its thick walls, double windows, etc. . . .

Thus it is easy to see that the question how great will be the temperature of the air at a given place, say in midwinter, when the distance of the sun is greater or less than at present, can not be answered, even approximatively, especially in the exceedingly crude way it is put by Dr. Croll—that is, without distinguishing high and low latitudes, continent and ocean, etc. One thing is certain, that such a change will certainly have a greater influence on the temperatures in the interior of continents than on the oceans and their borders. The caloric capacity of water is so great, and the mobility of its particles so effectual in resisting a lowering of the surface temperature, by the convection currents it causes, that I doubt very much if, during a great eccentricity and winter in aphelion, the surface temperature of the oceans can be lower in winter than now; the difference in the quantity of sun-heat is too small and too short-continued to give an appreciable difference in winter; and, as in the year there is no difference in the quantity of heat received by the waters, I think there will be no difference in the temperature of the waters, and thus no influence of great eccentricity with winter in aphelion on the ocean temperatures, and also no greater snow-fall than now. As to the continents, I admit that, though we are *unable to calculate the rate of decrease of temperature of the winter months* in these conditions, there is no doubt that *it will be appreciable, and be*

*the greater the less a given place is under the influence of the seas.**

We may test the theory still further by an appeal to geological facts. According to Mr. Croll, there must have been a succession of glacial periods in the past, and it would seem that numerous indications of such epochs, if they occurred, must exist in the successive geological strata. If such indications are not found in requisite amount, the advocates of Mr. Croll's theory are bound to give a satisfactory explanation of the failure.

To a consideration of this evidence Mr. Croll devotes the seventeenth and eighteenth chapters of his book on "Climate and Time," and at the outset confesses that "the facts which have been recorded as evidence in favor of the action of ice in former geological epochs are very scanty indeed." To account for this deficiency of evidence, he adduces, first, "the imperfection of the geological records themselves; and, second, the little attention hitherto paid toward researches of this kind."

Mr. Croll's presentation of the reasons, from the nature of the case, why the evidence of glaciation in the earlier geological periods should be in large degree obliterated, is probably as strong as can be made. He argues that the present land-surfaces in nearly all cases represent former ocean-beds, hence sedimentary strata deposited during the Glacial age must consist of the water-worn material which had been carried out from glacial streams into the bordering seas and oceans, so that the most distinct signs of glacial action which we could expect to find in sedimentary strata would be deposits of pebbles, forming conglomerate rocks, and the occurrence in these conglomerates of occasional angular fragments, such as could only be transported on ice.

Mr. Croll, also, very naturally, dwells upon the extent to which the land-surfaces exposed between two geological epochs must have suffered from denudation. Erosive agen-

* Woeikoff in "American Journal of Science," vol. cxxxi, pp. 169, 172.

cies would operate in the ordinary way during the whole period of elevation, the streams carrying down to the sea a large amount of material every season. But when the period of depression had proceeded so far as to bring the surface below the level of the sea, Mr. Croll believes the action of the waves would greatly hasten the operation, and would thoroughly sort out and roll the pebbles, washing the finer particles into deeper water.

A careful consideration of the forces in operation, however, does not seem wholly to justify this reasoning of Mr. Croll. In the first place, there must have been at various geological epochs, over the area now most studied, extensive land exposures, continuing through a long period of time. The Tertiary deposits contain many vegetable remains as well as animal, showing the existence of land areas of no small extent. The Carboniferous period reveals whole continents maintaining, over a large portion of their extent, an elevation near the sea-level, in which there were continual but slight oscillations, tending, however, on the whole to subsidence. So that land-plants accumulated in sufficient quantity to form the coal-beds—the periods of depression being marked by sedimentary rocks formed by the consolidation of the wash that was spread over the whole region during the times of depression.

Now, it does not seem possible that a glaciated area so extensive as is that of North America, and so deeply covered with glacial *débris*, could be so completely removed by ordinary denuding agencies that no more signs of it should appear than are found of such phenomena in the earlier geological epochs; for the till, or ground-moraine, is not readily removed by the action of water, even where subjected to the shore-waves of the ocean. The bowlders which are washed out of it form a protecting barricade around the base of the deposit, so that islands like those in Boston Harbor, composed wholly of till, are as nearly proof against the waves as are those of ordinary rocks. If there were in progress a subsidence of the glaciated area of North America, instead of

having the waves wash the glaciated surfaces away gradually from the edges inward, we should find merely an encroachment made here and there upon the border during a portion of the subsidence, until, finally, when the waters covered the whole, all but a very thin stratum of the upper portion would be protected from further disturbance. Especially must the till remain in the innumerable buried channels of the glaciated region, and over the extensive protected northern slopes. It is thus difficult to conceive how there should ever be any such complete removal of the ground-moraine from the immense glaciated area of North America as Mr. Croll supposes to have occurred several times over in preceding glacial epochs.

The facts supposed to prove, by direct evidence, the existence of glacial periods in the various successive geological epochs, can be briefly stated.*

Beginning with some of the oldest sedimentary strata, Professor Archibald Geikie has discovered what he believes to be unmistakable signs of glacial action in the north of Scotland, in Sutherlandshire, on rocks of Cambrian age—that is, just below the base of the Silurian system. Here he reports extensive surfaces of gneiss rock worn into the characteristic "rounded bossy surface" of glaciated regions, and this evidently runs under an extensive deposit of breccia of glacial origin, made up of fragments eroded by ice at that early period of glaciation.† Some of the fragments of this overlying breccia are said to be from five to six feet long.

A second instance of early glaciation, mentioned by Professor Ramsay, occurs in the south of Scotland, in Ayrshire and Wigtonshire, in the Lower Silurian formations of that region. Here are extensive sedimentary rocks, containing

* On the whole, the best summary of the evidence upon this subject, and the one to which we are mainly indebted for the facts here presented, was given by Sir A. C. Ramsay, Director-General of the Geological Survey of the United Kingdom, in his Presidential Address before the British Association of Swansea in 1880. (See "Nature," vol. xxii, p. 388 *et seq.*)

† See communication to "Nature," vol. xxii, pp. 400–403.

characteristic Lower Silurian fossils, in which are numerous erratic blocks of gneiss and granite, some of them as many as nine feet in length. Both Dr. Ramsay and Mr. James Geikie believe that the nearest source from which these fragments could come is one hundred miles or more to the north. Their theory is that, in the early Silurian times, the region occupied by the Hebrides and the adjoining coast of northern Scotland consisted of an immense granitic mountain uplift, down which glaciers descended to the sea, sending off bowlder-laden icebergs, which wandered to the vicinity of Ayrshire and Wigtonshire, and there dropped their burdens.

In India, also, according to Dr. Ramsay, Medlicott and Blanford describe "old slates supposed to be Silurian, containing bowlders in great numbers," which these experienced authorities believe to be of glacial origin. They also describe other very ancient transition beds which overlie rocks "marked by distinct glacial striations." Again, Dr. Ramsay describes bowlder-beds in the south of Scotland, on the Lammermoor Hills, south of Dunbar, which "contain what seem to be indistinctly ice-scratched stones." These beds lie "unconformably on Lower Silurian strata," and are now generally believed by the members of the Geological Survey of Scotland to be of glacial origin. Dr. Ramsay goes on to say:

I know of no bowlder formations in the Carboniferous series, but they are well known as occurring on a large scale in the Permian brecciated conglomerates, where they consist of pebbles and large blocks of stone, generally angular, imbedded in a marly paste; . . . the fragments have mostly traveled from a distance, apparently from the borders of Wales, and some of them are three feet in diameter. Some of the stones are as well scratched as those found in modern moraines or in the ordinary bowlder-clay of what is commonly called the Glacial epoch. In 1855 the old idea was still not unprevalent that during the Permian epoch, and for long after, the globe had not yet cooled sufficiently to allow of the climates of the external world being universally affected by the constant radiation of heat from its interior. For a long time, however, this idea

has almost entirely vanished, and now, in Britain at all events, it is little if at all attended to, and other glacial episodes in the history of the world have continued to be brought forward and are no longer looked upon as mere ill-judged conjectures.

The same kind of brecciated bowlder-beds that are found in our Permian strata occur in the Rotheliegende of Germany, which I have visited in several places, and I believe them to have had a like glacial origin.

Mr. G. W. Stow, of the Orange Free State, has of late years given most elaborate accounts of similar Permian bowlder-beds in South Africa. There great masses of moraine matter not only contain ice-scratched stones, but on the banks of rivers where the Permian rock has been removed by aqueous denudation the underlying rocks, well rounded and mammillated, *are covered by deeply incised glacier grooves* pointing in a direction which at length leads the observer to the pre-Permian mountains whence the stones were derived that formed these ancient moraines.

Messrs. Blanford and Medlicott have also given, in "The Geology of India," an account of bowlder-beds in what they believe to be Permian strata, and which they compare with those described by me in England many years before. There the Talchir strata of the Gondwana group contain numerous bowlders, many of them six feet in diameter, and in one instance *some of the blocks were found to be polished and striated, and the underlying Vindhyan rocks were similarly marked.* The authors also correlate these glacial phenomena with those found in similar deposits in South Africa, discovered and described by Mr. Stow.

In the Olive group of the Salt range, described by the same authors, there is a curious resemblance between a certain conglomerate "and that of the Talchir group of the Gondwana system." This "Olive conglomerate" belongs to the Cretaceous series, and contains ice-transported erratic bowlders derived from unknown rocks, one of which, a red granite, "is polished and striated on three faces in so characteristic a manner that very little doubt can exist of its having been transported by ice." One block of red granite at the Mayo salt-mines of Khewra "is seven feet high and nineteen feet in cir-

cumference." In the "transition beds" of the same authors, which are supposed to be of Upper Cretaceous age, there also are bowlder-beds with erratic blocks of great size.

I know of no evidence of glacial phenomena in Eocene strata excepting the occurrence of huge masses of included gneiss in the strata known as Flysch in Switzerland. On this question, however, Swiss geologists are by no means agreed, and I attach little or no importance to it as affording evidence of glacier ice.

Neither do I know of any Miocene glacier deposits excepting those in the north of Italy, near Turin, described by the late eminent geologist, Gastaldi, and which I saw under his guidance. These contained many large erratic bowlders derived from the distant Alps, which, in my opinion, were then at least as lofty as or even higher than they are now, especially if we consider the immense amount of denudation which they underwent during Miocene, later Tertiary, and post-Tertiary times.*

In North America Professor Shaler would attribute the conglomerates of Jurassic age in the valley of the Connecticut, in a part of which lie the celebrated bird-tracks, to glacial origin. This he infers, from the great thickness of the beds, the absence of life from the accompanying sandstones, the subangular forms of many of the pebbles, and from the similarity in composition of the pebbles of that conglomerate with that of those found in the modern drift of the region.† Upon this conclusion, however, it is proper to remark that the drift in the lower Connecticut Valley would, to a great extent, come from the same region, whether brought by ice or water, and the extent to which the pebbles would have been reduced to uniformity and smoothness by attrition depends upon the distance to which they have been rolled, or the length of time to which they have been subjected to wave-action. From what appears, the evidence is not clear that the fragments from which the pebbles are

* "Nature," vol. xxii, p. 389.

† See "Illustrations of the Earth's Surface: Glaciers," by N. S. Shaler and W. M. Davis. Boston: James R. Osgood & Co., 1881, p. 95.

made may not have originated in the near vicinity, and so their subangular condition need not imply glacial agency in transportation.

Professor Shaler also is inclined to attribute the extensive conglomerate deposits of the Carboniferous age in the Appalachian district of North America to glacial action; and certainly the extent of these conglomerate deposits underlying the coal-beds is surprising. "In Pennsylvania they are about one thousand feet; in eastern Kentucky and east Tennessee their thickness rises to about two thousand feet." Similar conglomerate deposits everywhere underlie the Carboniferous system. According to Professor Shaler, "we find it from southern France to Scotland, from Alabama to New Brunswick, in India, and elsewhere." For the most part, however, the pebbles of this conglomerate consist of quartz or quartzite, well rounded, and seldom of larger size than can readily be transported by water; though Professor Newberry is reported to have "found a bowlder of quartzite seventeen inches by twelve inches, imbedded in a seam of coal." Altogether it seems more likely that we have in these conglomerates underlying the Appalachian coal-fields of America the wash brought down by large rivers heading in the mountain plateau toward the north and east, of which the Archaean range on the Atlantic border, together with the hills of New England and the Adirondacks of New York, are but the remnants. That floating ice may have played some part in the streams coming down from these mountain-heights is not improbable; but it is doubtful whether the facts warrant us in inferring anything more.

Professor Shaler would also attribute a still lower series of conglomerates whose typical development is in eastern Tennessee and western North Carolina, and which rests unconformably upon Laurentian rocks, to glacial action; though he confesses that no scratched bowlders have yet been discovered in these deposits, but he writes: "Recollecting that we know of no force that is competent to bring together such masses of pebbles derived from a wide-spread surface save

glacial action, we are justified in believing that this deposit is a product of ice-action, though the waste has evidently been worked over by water since its production." The thickness of the deposits he estimates to be in some places nearly twenty thousand feet. These deposits correspond in age to the Roxbury conglomerates in Boston, which are about five hundred feet in thickness, and "are composed of materials derived from various points in eastern Massachusetts and southern New Hampshire. The pebbles are rarely over a foot in diameter." But Professor Shaler thinks "their frequently subangular forms and the wide range of substances associated together make it pretty clear that they have a glacial origin."

Upon this the same remark is applicable which was made in a preceding section, namely, that along this whole Appalachian border there were formerly Archæan highlands of indefinite height, of which the stumps are all that now remain in the present hills and mountains. The erosion of these mountains on their western flanks has furnished the material of the vast sedimentary deposits of the eastern part of the Mississippi basin. For all we know, the material spread out over this area of sedimentary rocks was all within reach of rivers coming down from Archæan heights, and so there is no necessity of supposing extensive glacial transportation from more northern water-sheds such as we are compelled to suppose in the glacial age of recent date. The same remark may be extended to all the evidence adduced in the preceding sections concerning a succession of glacial periods.* In all cases they are of such limited character that local glaciers coming down from isolated mountain-masses, such as now come down from the mountains of Alaska, Patagonia, and at no very distant date from those of New Zealand, are sufficient to account for the facts.

Returning to the point under discussion, it is proper to remark that the conclusions here presented with reference to

* See Lyell, "Principles of Geology," vol. i, pp. 203–210.

Mr. Croll's theory are those pretty generally adopted at the present time by the American geologists best qualified to interpret the facts. Thus, among the more eminent American geologists, Mr. G. K. Gilbert wrote, in 1883:

It deals with a series of physical laws and physical conditions which interact upon each other in an exceedingly complex way—in so complex a way that meteorologists, who have to deal with only a portion of them, do not claim and scarcely hope for a complete analysis of their combinations. The opportunities for arguing in a circle are most seductive, and the *a priori* probability that important considerations have been overlooked is not small.

The only manner in which so comprehensive and intricate an hypothesis can be established is by stimulating inquiry which shall lead to corroborative evidence, and this is precisely what Croll's hypothesis, after eight years of wide publicity, has failed to do. If it is true, then epochs of cold must have occurred with considerable frequency through the entire period represented by the stratified rocks; and iceberg drift, if no other traces, should have been entombed at numerous horizons. It has not been found, however, and of the eight horizons claimed by Croll to show evidence of glacial action, the treatise under consideration [A. Geikie's "Text-Book of Geology"] mentions only two with confidence, and two others with doubt. In the two instances to which queries are not attached, the phenomena appear to indicate local and not general glaciation. If the hypothesis is true, the cold of the Glacial epoch must have been many times interrupted by intervals of exceptional warmth, but little has been added to the evidence adduced by Croll for such an interruption, and in America, where there is now great activity in the investigation of glacial phenomena, the evidence of a *single* inter-glacial period is cumulative and overwhelming, while there is no indication whatever of more than one.*

With this agrees the opinion of President Chamberlin:

The various astronomical hypotheses seem to be the worse for increased knowledge of the distribution of the ancient ice-

* "Nature," vol. xxvii, p. 262.

sheet. I think I speak the growing conviction of active workers in the American field, that even the ingenious theory of Croll becomes increasingly unsatisfactory as the phenomena are developed into fuller appreciation. I think I may say this without prejudice, as one who, at a certain stage of study, was greatly drawn toward that fascinating hypothesis.

But the more we know and ponder upon the enormous development of ice upon the plains of northeastern America, and contrast it with the relatively feeble development and dispersion from the mountainous regions of Alaska, which now bear the greatest glaciers outside of the arctic regions, and the relative absence of such accumulations in northeastern Asia—in short, the more we consider the asymmetry of the ice distribution in latitude and longitude, and its disparity in elevation, the more difficult it becomes to explain the phenomena upon any astronomical basis, correlated though it be with oceanic and aërial currents and geographical features, by whatsoever of ingenuity.*

Professor Le Conte remarks, in similar strain :

Of the recurrence of many glacial epochs in the history of the earth there is as yet no reliable evidence, but much evidence to the contrary. It is true that what seem to be glacial drifts, with scored bowlders, etc., have been found on several geological horizons, but these are usually in the vicinity of lofty mountains, and are probably, therefore, evidence of *local* glaciation, not of a *glacial* epoch. On the other hand, all the evidence derived from fossils plainly indicates warm climates even in polar regions during all geological periods until the Quaternary. The evidence at present, therefore, is overwhelmingly in favor of the *uniqueness* of the Glacial epoch. This fact is the great objection to Croll's theory.†

All doubts, concerning the existence of carboniferous and cambrian glacial periods have, however, been removed by facts which have accumulated during the last twenty-five

* "Proceedings of the American Association for the Advancement of Science," vol. xxxv, p. 211.

† "Elements of Geology," p. 577

years. It is now well ascertained that there have been several glacial periods but at irregular and widely separated intervals. The irregularity of the intervals would indicate that the cause cannot be the astronomical changes which Mr. Croll had adduced, for they occur at regular intervals. The facts as summarized by Professor Coleman are as follows:*

(1) The Huronian rocks of Canada, which are the oldest sedimentary strata in existence, contain extensive conglomerates in every area mapped in northern Canada through a region 1,000 miles long from east to west and 750 miles broad. Some of the bowlders in this conglomerate are tons in weight, while striated pebbles are as characteristic of glacial deposits as can be found in any other age. Sir Archibald Geikie had also noted similar deposits of archæan age in Scotland. The deposits in Canada occur over hundreds of thousands of square miles.

(2) In rocks of early cambrian age extensive conglomerates such as would be formed from the petrification of glacial till are found in widely scattered regions, more specially of the southern hemisphere. From such deposits in China Mr. Baily Willis has recently brought back beautifully glaciated stones. But much larger areas in Australia and South Africa are covered with "tillite" of cambrian age. In South Australia Mr. Howchin has traced these deposits over an area extending 450 miles from north to south and 250 from east to west, with a thickness of 1,500 feet. In South Africa the cambrian tillite has been traced by Mr. Rogers over an area of 1,000 miles. In both regions the glaciated area lies near the 30th degree of latitude, and the movement of bowlders has apparently been from south towards the north. Similar, but less clearly defined cambrian tillite has been reported at various places about Lake Superior. In Australia the ice

*"Glacial Periods and Their Bearing on the Geological Theories," "Bulletin of the Geological Society of America," vol. xix, pp. 347-366.

movement evidently reached sea-level in regions which now have a warm temperate climate.

There was a glacial epoch of great intensity at the close of the carboniferous period, which has been studied with much care in India, Australia, South Africa and South America. In India bowlder conglomerates or "tillite" occur at points which are from 700 to 800 miles apart, or if those reported from Afghanistan be included, extending from latitude 35° to 16°, a distance of 1,500 miles. In Australia this permo-carboniferous tillite has been traced "widely in all the states of the Commonwealth, including the island of Tasmania to the south, with a range of latitude between 20° 30′ and 43°. Striated rock surfaces are often found under the old bowlder clay, the directions of the scorings indicating a motion of the ice in general from south to north, as might be expected; but in various places the ice-sheet or sheets reached the sea, large bowlders occurring in stratified shale, as if dropped from ice, and marine fossils being found in close connection with the beds containing bowlders."

The most remarkable glacial deposits of this age, however, or in some respects of any age, are found in South Africa, where fully 1,000,000 square miles are covered with tillite extending from 30° southeast for a distance of 800 miles. It is found in all the provinces "from the south of Cape Colony to the middle of the Transvaal or possibly the southern boundary of Rhodesia, and from Priesk, in Cape Colony, on the west to eastern Natal." The deposit is thin in the north, and thick in the south where, in Cape Colony, it reaches a thickness of 1,000 feet. No striated rock surfaces are found in the south, but they abound in the north. The deposits occur at elevations of from 3,000 to 6,000 feet above the sea, but along the southern margin the deposits were evidently laid down in water, whether salt or fresh has not been determined. The most surprising thing about these deposits in South Africa is that the transportation has been from the equator towards the

[illegible] 7 inches long, from [illegible] (A. P. Colman.)

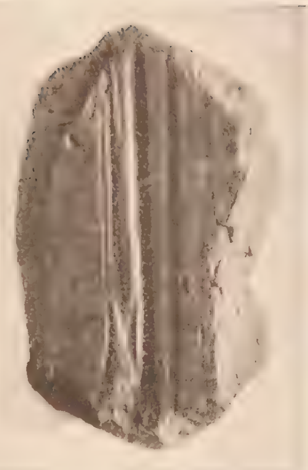

Fig. 130—Glaciated pebble, 11 inches long, from Dwyka, Matjesfontein, Cape Colony. (A. P. Colman.)

Fig. 131—Glaciated pleistocene surface from Lower Huronian tillite near Thessalon, Ont. (A. P. Colman.)

south pole. This was indicated by the fact just mentioned that they increased in thickness from north to south, as they do in the pleistocene glacial deposits of North America, though on different sides of the equator. But more decisive evidence appears in the direction of the scratches on the underlying rock, which is from northwest to southeast; and from the bowlders which have all been transported in the same direction.

In India also the ice movement of the permo-carboniferous period was from the equator northward, toward the pole, in some cases bowlders having been transported 750 miles in that direction.

Other indications of a permo-carboniferous period have been reported by Karpinsky and Tchernyschev in the Ural Mountains, and by Ramsay in England, but no one has discovered clear evidences of such deposits in America.

With reference to these deposits it is significantly remarked by Professor Coleman that "as in the pleistocene, there seems to have been an impressive grouping of the great ice-sheets in a special quarter, this time in the neighborhood of the present Indian Ocean; and their nearness to the equator, on low ground and reaching to the sea, makes it all the more puzzling that so little evidence of glacial work should be found in higher latitudes."

CHAPTER XIX.

THE CAUSE OF THE GLACIAL PERIOD—CONTINUED.

The eighth theory, which would attribute the growth and disappearance of glaciers entirely to changes in the distribution of land and water over the surface of the globe, was, according to his general principles, ably and ardently advocated by Sir Charles Lyell; and no one can read in his "Principles of Geology" the chapters upon this subject without being greatly impressed by the possible influences of such changes. The ocean is the great equalizer of the earth's temperature. Through unimpeded ocean-currents, like the Gulf Stream of the Atlantic and the Kuro-Siwa cf the Pacific, the heat of the tropics is transferred many thousands of miles to ameliorate the climate of even the polar regions. It is quite possible that comparatively slight changes in level in the vicinity of the West India Islands and Central America might so affect the direction of the Gulf Stream as to produce most serious modifications of the climate in North America and Europe. Should a portion of the Gulf Stream be driven through a depression across the Isthmus of Panama into the Pacific, and an equal portion be diverted from the Atlantic coast of the United States by an elevation of the sea-bottom between Florida and Cuba, the consequences would necessarily be incalculably great, so that the mere existence of such a possible cause for great changes in the distribution of moisture over the northern hemisphere is sufficient to make one hesitate before committing himself unreservedly to any other theory—at any rate, to one which has not for itself independent and adequate proof.

It is profitable, also, in this connection, to reflect on how delicately balanced the forces of Nature now are with respect to the production of glaciers. As already noted,* the glaciers existing at the present time in the Alps have their periods of advance and recession. A slight increase in the present snow-fall of Switzerland, if long continued, would produce alarming results. From this cause alone, the glaciers would at once begin to enlarge; and, in sympathy, the temperature would fall, and the increase of the glaciated area of Switzerland would go on until the whole country was again brought under the desolating reign of ice, or until the intervention of some counteracting force should stay its advance. It is not without reason, therefore, that some alarm was occasioned in Switzerland a few years ago by the proposition to inundate the Desert of Sahara. Fortunately, no extensive inundation of that region is within the reach of human power. But, if it could be inundated, thus extending greatly the evaporating area from which the clouds gather moisture for the Alpine heights, there is no telling what the result might not be. Should there be an annual increase of a foot of snow upon the Alps, a thousand additional feet of snow would have to be dissolved every thousand years, with the enormous absorption of heat accompanying the process. This simple calculation is sufficient to show the reality of the cause introduced by the eighth hypothesis, which would explain the Glacial period through the influence upon climate of changes in the distribution of land and water. This cause is so effective that it may even be conceived to be sufficient, without the introduction of any other agencies.

The ninth theory, which introduces considerable change of levels in the continents, rests, without doubt, upon a true cause, which, very likely, has coöperated with others, and may in itself have been the chief agency in producing the glacial conditions which we are studying. The evidence in support of this theory was so well presented by Dr. Warren

* See page 105.

Upham, in the appendix to the original edition of this volume and his conclusions have been supported by so many lines of evidence which have since come to light, that we now insert it in the body of the discussion with such supplementary notes as he has thought it necessary to add. It is a significant confirmation of his views that Professor Chamberlin's theory of the effect of the diminution of the carbonic dioxide in the atmosphere in producing glacial conditions involves extensive continental elevation of land surfaces as preliminary to the supposed depletion of this important element.

An examination of the evidence of changes in the relative heights of land and sea in various parts of the world during Quaternary time has led me to an explanation of the causes of the Glacial period, which, in this application of its fundamental principle, seems to be new, while in its secondary elements it combines many of the features of the explanations proposed by Lyell and Dana and by Croll. Briefly stated, the condition and relation of the earth's crust and interior appear to be such that they produce, in connection with contraction of the earth's mass, depressions and uplifts of extensive areas, some of which have been raised to heights where their precipitation of moisture throughout the year was almost wholly snow, gradually forming thick ice-sheets; but under the heavy load of ice subsidence ensued, with correlative uplift of other portions of the earth's crust; so that glacial conditions may have prevailed alternately in the northern and southern hemispheres, or in North America and Europe, and may have been repeated after warm interglacial epochs.

Quaternary oscillations of land and sea in glaciated regions have been discussed by Croll and Geikie on the assumption that the earth was so rigid that its form would not be changed by the load of the ice-sheet nor by its removal, which seemed more probable because of the well-known physical and mathematical researches of Hopkins, Thomson, Pratt, and Professor G. H. Darwin, who conclude that the earth is probably solid,

with not less rigidity than that of glass or steel. In deference to their researches, this conclusion is accepted and taught in recent text-books of geology by Le Conte and A. Geikie; but in similarly recent text-books Dana and Prestwich teach that the earth probably consists of a comparatively thin crust underlaid by a molten interior, which may change within a moderate depth to a great nucleal solid mass. Among other geologists and physicists who have discussed the condition of the earth's interior, King * and Shaler † believe it to be solid; while Whitney,‡ Dutton,# Powell, ‖ Wadsworth,△ Crosby, ◊ Gilbert,‡ Claypole, ‡ Airy, ‡ Fisher,** and Jamieson,†† believe that it is molten, or, at least, is surrounded by a molten layer, and that the earth's crust floats in a condition of hydrostatic equilibrium upon the heavier liquid or viscous mobile interior or layer enveloping the interior, subject, however, to strains and resulting deformation because of the earth's contraction. The thickness of the crust, according to this hypothesis, is variously estimated to be from twenty to fifty miles, or possibly a hundred miles or more.

It must be confessed that we have only a very inadequate knowledge of the conditions which would result from the enor-

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* "United States Geological Exploration of the Fortieth Parallel," vol. i, "Systematic Geology," 1878, pp. 117, 696–725.

† "Proceedings of the Boston Society of Natural History," 1866, vol. xi, pp. 8–15; 1868, vol. xii, pp. 128–136; 1874, vol. xvii, pp. 288–292. "Memoirs of the Boston Society of Natural History," 1874, vol. ii, pp. 320–340. "Scribner's Magazine," vol. iii, pp. 201–226, February, 1888.

‡ "Earthquakes, Volcanoes, and Mountain Building," 1871, pp. 77–87.

"Penn Monthly," vol. vii, pp. 364–378, and 417–431, May and June, 1876. "United States Geological Survey, Fourth Annual Report," pp. 183–198; "Sixth Annual Report," pp. 195–198.

‖ "Science," vol. iii, pp. 480–482, April 18, 1884.

△ "American Naturalist," vol. xviii, June, July, and August, 1884.

◊ "Proceedings of the Boston Society of Natural History," 1883, vol. xxii, pp. 443–485. "Geological Magazine," II, vol. x, 1883, pp. 241–252.

‡ "American Journal of Science," III, vol. xxxi, pp. 284–299, April, 1886.

‡ "American Naturalist," vol. xix, pp. 257–268, March, 1885. "American Geologist," vol. i, pp. 382–386, and vol. ii, pp. 28–35, June and July, 1888.

‡ "Nature," vol. xviii, pp. 41–44, May 9, 1878.

** "Physics of the Earth's Crust," 1881, pp. 223, 270, etc.

†† "Geological Magazine," III, vol. iv, 1887, pp. 344–348.

mous pressure and high temperature of the earth's interior, and wide diversity in speculations on this subject will probably long continue. Professor Shaler, while holding that the earth is mainly solid throughout, perhaps having in its most mobile layer beneath the crust "a rigidity such as belongs to the metals of average resistance to compression," yet is one of the earliest and most decided advocates of the opinion that the weight of an ice-sheet may depress the area on which it lies, and that the departure of the ice would be attended by re-elevation. In comparison, however, with the physical conditions and laws familiar to us upon the earth's surface, the subsidence and elevation of extensive areas, as of nearly all glaciated regions, seem to demonstrate a mobility of the earth's interior as if it were fused rock. The same conclusion is indicated by volcanoes, which are probably the openings of molten passages that communicate downward through the crust to the heavier melted interior, thence deriving their supply of heat, while their outpoured lavas consist largely or wholly of fused portions of the crust, the phenomena of eruption being caused by the access of water to the upper part of the molten rock near the volcanic vent. But the great plications of the strata in the formation of mountain-chains evidently involve only the upper part of the earth's crust, crumpled into smaller area in adapting itself to the diminishing volume of the lower portion of the same crust, which, with the nucleus, is undergoing contraction on account of the gradual loss of its heat, and perhaps also on account of progressing solidification and compression. There is in this process no dependence on the molten condition of the interior, except as that seems to be necessary for distortion of the earth, both of the crust and nucleus or mobile layer enveloping the nucleus, whereby considerable shrinkage of volume can take place before the accumulated strain becomes sufficient for the formation of a mountain-chain. At the present time depressions and elevations, probably caused by accumulating strains, are slowly changing the relations of land and sea upon many parts of the earth's surface. In the same way the downward and upward movements which would be caused by the burden of the ice-sheet and its removal are doubtless in many places complicated

by concomitant or subsequent movements thus due to deformations under strains, by which the elevation attributable to the departure of the ice-sheet may be augmented or partly or wholly counteracted, giving much irregularity to the glacial and post-glacial oscillations of the land.

Jamieson appears to have been the first, in 1865, to suggest this view, which I receive from him, that the submergence of glaciated lands when they were loaded with ice has been caused directly by this load pressing down the earth's crust upon its fused interior, and that the subsequent re-elevation was a hydrostatic uplifting of the crust by underflow of the inner mass when the ice was melted away.* Two years later Whittlesey published a similar opinion.† In 1868 Shaler referred the subsidence of ice-covered areas to a supposed rise of isogeothermal lines in the subjacent crust, operating, in conjunction with the ice-sheet, to produce downward flexure ;‡ but in 1874 and later he regards the depression as due directly to the weight of the ice, and the re-elevation as due to its removal.# The same view is advanced also by Chamberlin to account for the basins of the Laurentian lakes, where he believes a considerable part of the glacial depression to have been permanent.‖

* "Quarterly Journal of the Geological Society," vol. xxi, p. 178. Later discussions of this subject by Mr. Jamieson are in the "Geological Magazine," II, vol. ix, pp. 400–407 and 457–466, September and October, 1882 ; and III, vol. iv, pp. 344–348, August, 1887. In the article last cited, he applies this explanation to the changes of the beaches of Lake Agassiz, which up to that time I had attributed mainly to ice attraction. The same principle, however, was brought forward by Herschel in 1836, and had been advocated by Professor James Hall, of New York, in 1859, in attributing to the weight of sediments the long continued subsidence of the areas on which they have been deposited in great thickness.

† "Proceedings of the American Association for the Advancement of Science," vol. xvi, pp. 92–97.

‡ "Proceedings of the Boston Society of Natural History," vol. xii, pp. 128–136.

"Proceedings of the Boston Society of Natural History," vol. xvii, pp. 288–292 ; "Memoirs," ibid., vol. ii, pp. 335–340 ; "American Journal of Science," III, vol. xxxiii, pp. 220, 221, March, 1887 ; "Scribner's Magazine," vol. i, p. 259, March, 1887.

‖ "Geology of Wisconsin," vol. i, 1883, p. 290 ; "Proceedings of the American Association for the Advancement of Science," vol. xxxii, 1883, p. 212. The

Accompanying the subsidence of ice-loaded areas, there were doubtless uplifts of contiguous regions, perhaps sometimes including outer portions of the country glaciated. For example, the Quaternary elevation of which Le Conte finds evidence in the Sierra Nevada and northward may have been contemporaneous and correlative with depression of the northern parts of the continent beneath its ice-sheet. Furthermore, instead of being wholly offset by deformation of the crust, the glacial depression may have produced also extensive extravasation of lava, as is suggested by Jamieson * and Alexander Winchell,† for the vast Quaternary lava-flows of California, Oregon, Washington, and a large adjacent region. As Jamieson well remarks, this result would tend to cause a permanence of part of the depression of the ice-covered area. However it may have been caused, probably such permanent Quaternary subsidence is true for the coasts of many glaciated countries, as shown by fiords, and for the basins of the Laurentian lakes, which, excepting Erie, are depressed several hundred feet below the level of the ocean.

One of the most interesting fiords of North America is that of the Saguenay, tributary to the St. Lawrence. Along a distance of about fifty miles the Saguenay is from 300 to 840 feet deep below the sea-level; its adjoining cliffs rise abruptly in some places 1,500 feet above the water; and the width of its wonderfully sublime and picturesque gorge varies from about a mile to one mile and a half.‡ This fiord, like the many which indent our Eastern coast from Maine to Labrador and Greenland, and our Western coast from Puget Sound to the Arctic Ocean, was eroded by a stream that flowed along the bottom of the gorge when it was above the sea; and this erosion was probably going forward in the epoch immediately preced-

problems of ice attraction and of deformation of the earth's crust have been further discussed by President Chamberlin before the Philosophical Society of Washington, March 13, 1886; and, jointly with Professor Salisbury, in the "Sixth Annual Report, United States Geological Survey," pp. 291–304.

* "Geological Magazine," II, vol. ix, 1882, p. 405.

† "American Geologist," vol. i, pp. 139–143, March, 1888.

‡ "J. W. Dawson, "Notes on the Post-Pliocene Geology of Canada," 1872, p. 41.

ing the Ice age, for earlier subsidence during any period of much length, geologically speaking, would have caused the submerged valley to be filled with sediments. The preglacial elevation of the Saguenay region therefore appears to have been at least 1,000 feet greater than now; and it seems to be similarly proved by fiords that nearly the entire extent of the continental glaciated area was considerably higher before than after glaciation.

There is also evidence that part of the Atlantic coast of the United States close south of the limits of glaciation was at least for a short time preceding the Glacial period uplifted much above its present height. The submarine Hudson River fiord * indicates that the vicinity of New York and Philadelphia then stood 2,800 feet above the sea, and that it afterward slowly sank 1,600 feet, while a bar of that height was formed by coastwise wash across the mouth of the fiord. In this remarkable preglacial elevation, and in its being more or less shared by the whole northern half of the continent, the formation of the North American ice-sheet seems to be explained. If this was the cause of glaciation, probably the formerly greater height of about 1,000 feet on the Saguenay was not exceptional. Indeed, the elevation there and over large portions of the vast territory of Canada, bounded on the east, north, and west by fiord-indented coasts, may have been much more than is measured by the depth of the Saguenay River.

Going a step further back, we may regard this northward elevation as a distortion of the earth's form in the storage of energy of lateral pressure which culminated, with the introduction of the new factor of northward depression by the ice weight, in the Quaternary uplifts of the Western plains, the Rocky Mountains, the Sierra Nevada, and the Great Basin. These important changes in the elevations of great areas during the comparatively short Quaternary period seem to be consistent only with the hypothesis that our globe has a comparatively thin crust and a molten interior.

In the Glacial period significant changes of the sea-level

* A. Lindenkohl, "American Journal of Science," III, vol. xxix, pp. 475–480, with plate, June, 1885.

were caused: first, by abstraction of water from the ocean and its deposition on the land as snow, which under pressure made the vast ice-sheets; and, second, by ice attraction of the ocean, lowering it still further, except in the vicinity of glaciated lands. An area of about 4,000,000 square miles in North America, and another of about 2,000,000 square miles in Europe, were covered by ice-sheets, which in their maximum extent had probably an average thickness of a half or two thirds of a mile, or perhaps even of one mile. Assuming that these ice-sheets were contemporaneous, but disregarding ice-fields of smaller extent, which probably existed in parts of Asia and of the southern hemisphere, as also the glaciers of mountain districts, the lowering of the ocean surface, which covers approximately 145,000,000 square miles, would slightly exceed 100 feet, if the mean depth of the ice accumulation was half a mile. More probably the sea over the whole globe was thus depressed fully 150 feet, which would correspond to an average of about 3,600 feet of ice on the glaciated areas of North America and Europe. For the second factor in causing such changes, Mr. R. S. Woodward's computations* indicate that gravitation toward the ice would further depress the ocean probably twenty-five to seventy-five feet within the tropics and in the southern hemisphere, while it would raise the level enough near the borders of the ice-sheets to counterbalance approximately the depression due to the diminution of the ocean's volume, and would lift portions of the North Atlantic and of the Arctic Sea perhaps two or three hundred feet higher than now. Stream erosion while the sea was lowered to supply the ice of the Glacial period may explain the indentations of the southeastern coast of the United States, as Pamlico and Albemarle Sounds, besides similar inlets in many other parts of the world; but the excavation of Chesapeake and Delaware Bays seems more probably referable, at least in part, to the time of preglacial elevation, with the channeling of the now submerged Hudson fiord.

When the ice-sheet of the last Glacial epoch finally re-

* "United States Geological Survey, Sixth Annual Report," pp. 291–300; and "Bulletin No. 48," "On the Form and Position of the Sea-Level."

treated, the land which it had covered stood mostly lower than now, as is shown by the occurrence of fossiliferous marine deposits overlying the glacial drift up to considerable elevations. Near Boston, and northeast to Cape Ann, the coast seems to have been submerged to a slight depth, probably not exceeding ten to twenty-five feet. Proceeding toward the north and northwest, the elevation of the marine beds lying on the glacial drift increases to about two hundred and twenty-five feet in Maine, about five hundred and twenty feet in the St. Lawrence Valley at Montreal, and four hundred and forty feet at a distance of one hundred and thirty miles west-southwest of Montreal; but eastward, along the St. Lawrence, it decreases to three hundred and seventy-five feet opposite the Saguenay, and does not exceed two hundred feet in the basin of the Bay of Chaleurs; while these marine deposits are wanting in Nova Scotia and Cape Breton Island.* This subsidence accords well with the explanation that it was due to the pressure of the ice-weight, which was greatest on the highlands between the St. Lawrence and Hudson Bay.

Along the East Main coast of Hudson Bay and on Hudson Strait raised beaches are conspicuous, according to Dr. Robert Bell, up to heights of at least three hundred feet.† In the region draining from the southwest to James Bay, Dr. Bell reports marine shells in stratified beds overlying the glacial drift along the Moose, Mattagami, and Missinaibi Rivers up to about three hundred feet above the sea;‡ along the Albany

* A. S. Packard, Jr., "Memoirs of the Boston Society of Natural History," vol. i, pp. 231–262. J. W. Dawson, "Notes on the Post-Pliocene Geology of Canada"; and "American Journal of Science," III, vol. xxv, 1883, pp. 200–202. C. H. Hitchcock, "Proceedings of American Association for the Advancement of Science," Portland, 1873, vol. xxii, pp. 169–175; "Geology of New Hampshire," vol. iii, pp. 279–282; and "Geological Magazine," II, vol. vi, 1879, pp. 248–250. R. Chalmers, "Transactions of the Royal Society of Canada," sec. iv, 1886, pp. 139–145. W. Upham, "Proceedings of Boston Society of Natural History," vol. xxiv, pp. 127–141, December, 1888; "American Journal of Science," May, 1889.

† "Geological and Natural History Survey of Canada, Report of Progress for 1877–'78," p. 32 C; for 1882–'83–'84, p. 31 DD.

‡ "Geological and Natural History Survey of Canada, Report of Progress for 1875–'76," p. 340; for 1877–'78, p. 7 C.

and Kenogami Rivers up to a height of about four hundred and fifty feet;* and on the Attawapishkat to about five hundred feet above the sea.† It is also evident that the shores of Hudson Bay are still undergoing elevation,‡ unlike the eastern coast of the United States and Canada, where the post-glacial uplifting has ceased, and there is now in progress a very slow subsidence of the land from New Jersey to the Gulf of St. Lawrence.

Scantier but yet conclusive proofs of the uplift of British Columbia after glaciation are found in the valley of the Fraser River, and on the Pacific coast, in Vancouver Island and the Queen Charlotte Islands. Lamplugh has observed recent marine shells in a railway cutting on the west bank of the Harrison River, near its junction with the Fraser, at an elevation not less than one hundred feet above the sea.# At New Westminster, on the Fraser, near its mouth, raised beaches inclosing fragments of marine shells are reported by Bauerman about thirty feet above the river.‖ Fossiliferous marine deposits found in the vicinity of Victoria and Nanaimo, in the southeast part of Vancouver Island, at small elevations above the sea, are believed by Dr. G. M. Dawson to have been formed at or near the wasting edge of the ice-sheet;^ and near the middle of the northeast side of this island two distinct deposits of till occur, with intervening beds of loess-like silts, from which

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* "Geological and Natural History Survey of Canada, Report of Progress for 1871–'72," p. 112; for 1875–'76, p. 340; "Annual Report," vol. ii, for 1886, pp. 34 and 38 G.

† "Geological and Natural History Survey of Canada, Annual Report," vol. ii, p. 27 G.

‡ "Geological and Natural History Survey of Canada, Report of Progress for 1877–'78," pp. 32 C and 25 CC; for 1878–'79, p. 21 C; for 1882–'83–'84, pp. 26 and 30 DD; "Annual Report," vol. i, for 1885, p. 11 DD.

"Quarterly Journal of the Geological Society," vol. xlii, 1886, pp. 284, 285.

‖ "Geological and Natural History Survey of Canada, Report of Progress for 1882–'83–'84," p. 33 B.

^ "Geological and Natural History Survey of Canada, Annual Report," vol. ii, for 1886, p. 99 B; "Quarterly Journal of Geological Society," vol. xxxiv, 1878, pp. 97, 98, and vol. xxxvii, 1881, p. 279. Compare also Mr. G. W. Lamplugh's observations of glacial shell-beds at Esquimault, near Victoria, "Quarterly Journal of Geological Society," vol. xlii, 1886, pp. 276–284

this author infers two periods of glaciation, separated by an interglacial epoch, in which the land was submerged from one to two hundred feet.* Again, in the northeast part of the Queen Charlotte Islands Dr. Dawson finds evidence of submergence to the amount of two or three hundred feet, while the glacial conditions still endured.†

In Europe the glaciated area stood at a greater height before the Ice age, as is shown by fiords; it was similarly depressed while loaded with the ice-sheet; and since then it has been partially re-elevated. Its maximum post-glacial uplift known in the British Isles, so far as it has not been counteracted by subsequent depression, is five hundred and ten feet, near Airdrie, in Lanarkshire, Scotland;‡ and in Scandinavia it is about six hundred feet.# As in all the North American districts noted, these upward movements seem attributable to the rise of the earth's crust, upborne by inflow of a molten magma beneath.

But the derivation of the floras of the Färöe Islands, Iceland, and even Greenland from the flora of Europe, demonstrates, according to Professor James Geikie, that the portion of the earth's crust extending from Britain and Scandinavia to Greenland was uplifted in early post-glacial times about

* "Geological and Natural History Survey of Canada, Annual Report," vol. ii, p. 105 B.

† "Geological and Natural History Survey of Canada, Report of Progress for 1878–'79," p. 95 B. Further important notes of recent changes in level of the coast of British Columbia, and of Washington Territory and Alaska, are given by Dr. Dawson in the "Canadian Naturalist," new series, vol. viii, pp. 241–248, April, 1877. He concludes that this area had a preglacial elevation at least about nine hundred feet above the present sea-level, during part or the whole of the Pliocene period, this being indicated by the fiords; that it was much depressed in the Glacial period; and that in post-glacial time it has been re-elevated to a height probably two or three hundred feet greater than now, followed by subsidence to the present level, the latest part of this oscillation being a somewhat rapid depression of perhaps ten or fifteen feet during the latter part of last century—a movement which may still be slowly going on.

‡ "Quarterly Journal of the Geological Society," vol. vi, 1850, pp. 386–388, and vol. xxi, 1865, pp. 219–221; "American Geologist," vol. ii, pp. 371–379, December, 1888.

"Geological Magazine," I, vol. ix, 1872, p. 309; and II, vol. ii, 1875, p. 390.

three thousand feet higher than now;* and the same author shows that in interglacial time tropical animals passed from Barbary into Spain upon land where now the Strait of Gibraltar has a depth of one thousand feet.† These changes in the relations of land and sea can not be ascribed to glaciation, but seem to be distortions of the earth's form, such as may be attributed to the action of strain upon the crust by which the earth can become reduced in volume through the subsidence and elevation of extensive areas during intervals between epochs of mountain-building. In the same class of changes are also to be included, wholly or in part, the postglacial elevation of Grinnell Land and the northwestern coast of Greenland, one thousand to sixteen hundred feet;‡ post-Pliocene upward movements of two thousand feet or more in Jamaica and Cuba;# the recent uplift of the coast of Peru at least twenty-nine hundred feet,‖ which in diminished amount seems to extend along the whole range of the Andes; its probable connection with the upheaval of the Cordilleras of North America, where Le Conte believes that the elevatory movements reached their greatest intensity in early Quaternary time, causing a rise of several thousands of feet in the Sierra Nevada;△ and the apparently correlative subsidence of a great

* "Prehistoric Europe," pp. 513–522, and 568, with Plate E.

† "Prehistoric Europe," pp. 325, 337–339; "Quarterly Journal of the Geological Society," vol. xxxiv, 1878, p. 505.

‡ "Quarterly Journal of Geological Society," vol. xxxiv, 1878, p. 66; "Geological Magazine," III, vol. i, 1884, p. 522.

\# J. G. Sawkins, "Reports on the Geology of Jamaica," 1869, pp. 22, 23, 307, 311, 324–329; W. O. Crosby, "On the Mountains of Eastern Cuba," "Appalachia," vol. iii, pp. 129–142. Compare William M. Gabb's memoir, "On the Topography and Geology of Santo Domingo," "Transactions of the American Philosophical Society," vol. xv, pp. 103–111.

‖ A. Agassiz, "Proceedings of the American Academy of Arts and Sciences," vol. xi, 1876, p. 287; and "Bulletin of the Museum of Comparative Zoölogy, at Harvard College," vol. iii, pp. 287–290. Above this height, at which corals are found attached to rocks, recent elevation of much greater amount seems to be indicated by terraces, by saline deposits, and by the presence of eight species of Allorchestes—a genus of marine crustacea, in Lake Titicaca, 12,500 feet above the sea.

△ "American Journal of Science," III, vol. xxxii, pp. 167–181, September, 1886.

area dotted with coral islands in the Pacific. The Quaternary uplifts of the Andes and Rocky Mountains and of the West Indies make it nearly certain that the Isthmus of Panama has been similarly elevated during the recent epoch. On the line of the Panama Railway the highest land rises only two hundred and ninety-nine feet above the sea, and the highest on the Nicaragua Canal is about one hundred and thirty-three feet, while the isthmus nowhere attains the height of one thousand feet.* It may be true, therefore, that the submergence of this isthmus was one of the causes of the Glacial period, the continuation of the equatorial oceanic current westward into the Pacific having greatly diminished or wholly diverted the Gulf Stream, which carries warmth from the tropics to the northern Atlantic and northwestern Europe.

In view of the extensive recent oscillations of land and sea both in glaciated and unglaciated regions, it seems a reasonable conclusion that, while some of these movements have resulted directly from the accumulation and dissolution of ice-sheets, more generally, when the whole area of the earth is considered, they have been independent of glaciation. May not such movements of the earth's crust, then, have elevated large portions of continents, as the northern half of North America and the northwestern part of Europe, to heights like those of the present snow-line on mountain-ranges, until these plateaus became deeply channeled by fiords and afterward covered by ice-sheets? For the recentness of the latest glaciation, believed to have ended in the northern United States not more than ten thousand to six thousand years ago,† forbids our re-

* Charles Ricketts, "The Cause of the Glacial Period, with reference to the British Isles," "Geological Magazine," II, vol. ii, 1875, pp. 573–580. A. R. Wallace, "The Geographical Distribution of Animals," vol. i, p. 40.

† N. H. Winchell, "Geology of Minnesota," "Fifth Annual Report," for 1876, and "Final Report," vol. ii, pp. 313–341; "Quarterly Journal of the Geological Society," vol. xxxiv, 1878, pp. 886–901. E. Andrews, "Transactions of the Chicago Academy of Sciences," vol. ii. James C. Southall, "The Epoch of the Mammoth and the Apparition of Man upon the Earth," 1878, chaps. xxii and xxiii. G. F. Wright, "American Journal of Science," III, vol. xxi, pp. 120–123, February, 1881; "The Ice Age in North America," chap. xx. G. K. Gilbert, "Proceedings of the American Association for the Advancement of Science," vol. xxxv, 1886.

ferring the glacial climate to conditions brought about by a period of increased eccentricity of the earth's orbit from two hundred and forty thousand to eighty thousand years ago, which has been so ably maintained by Croll and Geikie; and some other adequate cause or causes must be sought for the successive Quaternary glacial epochs of these great continental areas and other districts of smaller extent both in the northern and southern hemispheres; also for the rare occurrence of glacial conditions in various portions of the earth during past geologic ages, especially in the Carboniferous and Permian periods. The principal cause of all these epochs of glaciation seems to the writer to be probably found by the clew supplied in the relations already stated of the earth's crust and interior, whereby they become somewhat distorted from the spheroidal form while the process of contraction goes forward, the lateral pressure bearing down some portions of the earth's surface, and uplifting other extensive areas. Protuberant plateaus, swept over by moisture-laden winds, would be the gathering-grounds of vast ice-sheets, which would probably wax and wane with the changes of the earth's attitude toward the sun, by which the earth's place in any season, as summer, alternates from aphelion to perihelion, and back to aphelion in cycles of twenty-one thousand years. A similar explanation of the Glacial period was long ago proposed by Lyell and Dana, but without referring the elevatory movements to the earth's deformation by contraction and accumulating lateral pressure while approaching an epoch of mountain-building, which fundamental principle was first suggested to me in an article from the pen of Professor W. O. Crosby, on the origin and relations of continents and ocean basins.*

During the periods immediately preceding great plications and shortening of segments of the earth's crust involved in the formation of lofty mountain-ranges, the broad crustal movements causing glaciation would be most wide-spread and attain their maximum vertical extent. The accumulation of ice-sheets may have brought about the depression of their areas,

* "Proceedings of the Boston Society of Natural History," 1883, vol. xxii, pp. 455–460.

with corresponding elevation of other plateaus, which in turn would become ice-covered, so that the epochs of glaciation of the northern and southern hemispheres may have alternated with each other;* and this may have been several times repeated, because of crustal oscillations due to ice-weight and its removal, the effects of elevation and depression of the land being re-enforced by climatic influences arising from the revolution each twenty-one thousand years in the place of the seasons. When the building up of a great range of mountains ensued, which may have been initiated and accelerated by the repeated depressions under ice-weight and consequent transfers of the earth's deformation from one region to another, the accumulated strain in the earth's crust, with development of immense lateral pressure, would be diminished below the limit of its competency to cause glaciation.

Such Quaternary mountain-building is known to have occurred on a most massive scale in Asia, where the Himalayas, stretching fifteen hundred miles from east to west, and towering twenty thousand to twenty-nine thousand feet above the sea, are known to have been formed, at least in great part, and perhaps almost wholly, during this latest geologic period,† contemporaneously with the glaciation of North America, Europe, and portions of the southern hemisphere. Within the same time the great table-land of Thibet,‡ and much of central and northwestern Asia, have been uplifted; the tract extending from the Black and Caspian Seas northeast to the Arctic Ocean has risen to form a land-surface; and the deep basin of Lake Baikal has been probably formed in connection with these crustal movements. Accompanying the formation of the Himalayas, there has been doubtless much disturbance by faults, local uplifts, and here and there plication of strata

* Compare the opinions of Hutton, cited in A. Geikie's "Text-Book of Geology," second edition, p. 912, that the former greater extension of glaciers in New Zealand was caused by an increase in the elevation of the land, and that it belonged to a much earlier time than the Ice age in the northern hemisphere, probably to the Pliocene period.

† "Manual of the Geology of India," by H. B. Medlicott and W. T. Blanford, Calcutta, 1879, Part I, pp. lvi, 372; Part II, pp. 569–571, 667–669, 672–681.

‡ Ibid., Part II, pp. 585, 586, 669–672.

along the whole complex east to northwest and west mountain system of Oceania, Asia, Europe, and Northern Africa, from New Guinea, the Sunda Islands, Anam, and Siam, to the Caucasus, Carpathians, Balkans, Apennines, Alps, Pyrenees, and Atlas Mountains, stretching quite across the eastern hemisphere; but the greater part of the relief from the previously existing deformation of the earth was doubtless along the central part of the belt, in the colossal Himalayan range. In like manner the North American Cordilleras and the Andes, reaching in one continuous mountain system from the Arctic Circle to Cape Horn, have experienced within the same period great disturbances, as already noted, similar to those of the mountains of Southern Europe and the adjacent part of Africa. With this American orographic belt is also probably to be associated the mountain system, consisting largely of volcanoes now active, which forms the Aleutian Islands, Kamtchatka, the Kurile Islands, Japan, Formosa, the Philippines, Borneo, and Celebes, lying nearly in the same great circle with the Andes and Rocky Mountains, and with them continuous in an arc of about two hundred and forty degrees. Along two lines transverse to each other, one having an extent of half and the other of two thirds of the earth's circumference, the great lateral pressures of the earth's crust, which probably caused the elevation and glaciation of extensive areas during the Quaternary period, have been relieved by plication, faults, and uplifts, in the processes of the formation of mountain-ranges.*

Combined with oscillations of the earth's crust, which are here regarded as the primary cause of the growth and decline of ice-sheets, many other concomitant conditions, notably changes in aerial and oceanic currents, and the earth's cycles of twenty-one thousand years through precession and nutation, enter into the complex causation of recurrent glacial and interglacial epochs, and serve to intensify or to mitigate the severity of the glaciation due to elevation. The influences of these conditions would be nearly the same that are claimed for them

* See Prestwich's "Geology," vol. i, chap. xvii, treating of the relative ages of the principal mountain-ranges of the world.

in the luminous glacial theory of Croll, but their origin and effectiveness toward causing a glacial climate are here referred to extensive crust oscillations instead of eccentricity of the earth's orbit. The prolonged warm interglacial epoch, or several such epochs, of which evidence is obtained in the Quaternary deposits of Europe and North America, preceded and followed by severe arctic climate and ice-sheets, meet an adequate and consistent explanation in the view here taken; and, indeed, the same reasoning that is presented by Croll in the details of the secondary elements of his theory seems equally applicable if these depend primarily on crustal elevation.

The principal interglacial epoch in the United States, under this view, may well have been several times longer than either the previous or subsequent epochs of glaciation, or than the whole of post-glacial time, as claimed by McGee;* but it does not follow that an exact parallelism will be found in the glacial history of Europe. Former extension of vast glaciers in the Rocky Mountains and Andes, the Pyrenees and Alps, the Atlas range, the Caucasus, the Himalayas, and elsewhere, far exceeding the glaciers of the present time, may be due to the uplift of these mountains much above their present height, followed by subsidence † with retreat of the ice; but these oscillations and resulting alternations of climate were not probably synchronous everywhere. The highest mountain-ranges in four grand divisions of the world—namely, Asia, Europe, and North and South America—were doubtless largely uplifted and plicated, with formation of deep adjoining lakes, during the early part of the Quaternary period. Twice upheavals of the whole district of the Alps seem to have covered the region with great accumulations of ice, which each time may have depressed the area, first to be succeeded by the formation of interglacial deposits with lignite, and during each depression to send down floods, spreading loess along the Rhine, the Rhone, and the Danube.‡ After the later epoch of subsidence and glacial re-

* "American Journal of Science," III, vol. xxxv, pp. 463–466, June, 1888.

† A. Geikie's "Text-Book of Geology," second edition, p. 934.

‡ J. Geikie's "Great Ice Age," second edition, chapters xxxiii and xxxiv, and his "Prehistoric Europe," chapters ix and xi.

cession, there seems to have been a renewal of elevation, as shown by the height and slopes of the loess.

Asia had no extensive ice-sheet like those of Europe and North America, probably because a sufficient elevation was not attained there until the Himalayas and Thibet were uplifted in the Glacial period. Their southern latitude and the position of Thibet and Mongolia in an arid and partly rainless belt, which stretches thence west to the Sahara, forbade their glaciation; but from these recently uplifted Asiatic table-lands and mountains the most extensive Quaternary deposits of the world have been brought down by rivers and spread in the vast low plains of Siberia, eastern China, and northern India, sloping gently toward the sea, into which the finer part of this alluvium is carried. All the puzzling features of the Chinese loess formation,* reaching to great elevations with such thickness and slopes of its surface that it could not be so accumulated as alluvium of flooded streams under the present conditions, seem to be readily explained by referring its deposition to annual floods from immense snow-melting, during the European Glacial epochs, upon the gradually rising central part of the Asiatic Continent, which consists largely of easily erosible strata, and had in preglacial time become extensively disintegrated by weathering under a dry climate.

With this reference of glaciation primarily to oscillations of land, a new element of Quaternary history is introduced, which seems to help much in accounting for peculiarities in the areal distribution of identical or closely allied species of animals and plants that have doubtless sprung from a common source but have now become widely separated. Not only are we able to follow Gray in his tracing the origin of the big trees of California, of the species in the flora of the eastern United States—which are the same with species of Japan, China, and the Himalayan region, or are represented there by closely related forms, though unrepresented in Europe—and of mount-

* Baron Richthofen, "Geological Magazine," II, vol. ix, 1882, pp. 293–305. J. D. Whitney, "American Naturalist," vol. xi, pp. 705–713, December, 1877. R. Pumpelly, "American Journal of Science," III, vol. xvii, pp. 133–144, February, 1879. E. W. Hilgard, "American Journal of Science," III, vol. xviii, pp. 106–112, August, 1879.

ain plants identical with those of the Arctic zone ;* but also we may now more satisfactorily bridge over the tropics and equator, by uplifts and subsidences of mountain-ranges, so that species incapable of enduring a torrid climate could sometimes become dispersed even to such distances as from north temperate latitudes to Tierra del Fuego and the Cape of Good Hope.†

It seems probable that the rate of the earth's contraction has been somewhat uniform throughout the vast ages known to us by the researches of geology ; but the corrugation of the earth's surface in mountain-building has been much more rapid in some epochs than in others, and between the times of formation of great mountain-ranges there have been long intervals of quietude. ‡ The slowly progressing contraction of the globe has been uninterrupted, and in some way the cooled outer part of the crust which has not shared in this diminution of volume has been able to accommodate itself to the shrinking inner mass. As stated on a previous page, this has probably resulted in distortion of the earth's form, both of the whole thickness of the crust and of the probably molten interior, within moderate limits during the periods of quiet, until so much lateral pressure has been accumulated as to compress, fold, and uplift the strata of a mountain-range. In attributing the severe climate of glacial epochs to great uplifts of the areas glaciated through such deformation preparatory to the process of mountain-building, it is distinctly implied that the Quaternary period has been at first exceptionally marked by such broad crustal movements, and has since gained comparative rest from the lateral stress to which they were due by equally exceptional

* "Sequoia and its History," "Proceedings of the American Association for the Advancement of Science," Dubuque, vol. xxi, 1872, and "American Journal of Science,"' III, vol iv ; "Forest Geography and Archæology," "American Journal of Science," III, vol. xvi, 1878 ; "Characteristics of the North American Flora," "Report of the British Association for the Advancement of Science," Montreal, 1884, and "American Journal of Science," III, vol. xxviii.

† Darwin's "Origin of Species," chapter xi. Wallace's "Geographical Distribution of Animals," chapter iii, and his "Island Life," chapter vii.

‡ Dana's "Manual of Geology," third edition, p. 795 ; Prestwich's "Geology," vol. i, chap. xvii.

plication, uplifts, and faults in the birth and growth of mountains. Further, it is implied also that stress in the earth's crust had been gradually increasing through long previous time, while the processes of mountain-building failed to keep pace with contraction, but were still sufficient to keep the earth's deformation less than is required to produce glaciation; for no evidences of intense and widely extended glacial conditions are found in the great series of Tertiary and Mesozoic formations, representing the earth's history through probably ten or fifteen millions of years. And indeed these conclusions, drawn from the Quaternary Glacial period and the absence of glaciation through vast eras preceding, accord well with the known age and stages of growth of mountain-ranges that have been formed during these eras. No epoch since the close of Palæozoic time has been more characterized by mountain-building than the comparatively short Quaternary, whose duration may probably be included within one hundred thousand or two hundred thousand years. The continuation of the earth's faunas and floras, with only very slight changes of species and exceedingly rare instances of extinction through the Quaternary period, notwithstanding its remarkable vicissitudes of climate and changes in the relative heights of land and sea, which seem especially adapted to produce both modifications and extinctions of organic forms, bears indisputable testimony of the brevity of this period, when compared with those of Tertiary and Mesozoic time. As we extend our investigations backward in the geologic record, the species now existing are found in decreasing numbers until we come to the beginning of the oldest. In their places very different species, genera, orders, and groups tenanted the earth before them; and the gradual and doubtless very slow evolution of the present from the past must have required duration almost incommensurable by years and centuries. But the total of mountain-building that has taken place during the Mesozoic and Tertiary eras is disproportionately small in comparison with that of the Quaternary period, even when ample allowance is made for long and very great denudation.

Not until we go back to the Permian and Carboniferous periods are numerous and widely distributed proofs of very

ancient glaciation encountered. The atmosphere had been purified by the formation of Palæozoic limestones of great thickness, and by the storing up of the principal coal-deposits of the world; and these changes in the air had quite surely produced greater diversities of climate than before existed, especially in respect to the range of temperature in the seasons and in the several zones. Alternating beds of coal, shales, and sandstones, which form the coal-measures, indicate oscillations of level and climatic conditions much like those of the Quaternary period;* and bowlder-bearing deposits, sometimes closely resembling till and including striated stones, while the underlying rock also occasionally bears glacial grooves and striæ, are found in the Carboniferous or more frequently the Permian series in Britain, France, and Germany,† Natal,‡ India,# and southeastern Australia.‖ In Natal the striated glacier floor is in latitude 30° south, and in India only 20° north of the equator. During all the earth's history previous to the Ice age, which constitutes its latest completed chapter, no other such distinct evidences of general or interrupted and alternating glaciation have been found; and just then, in close relationship with extensive and repeated oscillations of the land, and with widely distant glacial deposits and striation, we find a most remarkable epoch of mountain-building, surpassing any other time between the close of the Archæan era and the Quaternary. The Appalachian Mountain system of the United States, with its grand plications and upheaval of the whole Palæozoic group of rocks, belongs to this epoch, and the same line of disturbance extends by faulting and uplifts northeastward to Gaspé and Newfoundland. In Europe

* Croll's "Climate and Time," chap. xxvi.

† "Climate and Time," chap. xviii; Wallace's "Island Life," chap. ix.

‡ "Quarterly Journal of the Geological Society," vol. xxvi, 1870, pp. 514–517; vol. xxvii, 1871, pp. 57–60.

"Manual of the Geology of India," Part I, pp. xxxv–xxxviii, 102, 109–112, 229.

‖ "Quarterly Journal of the Geological Society," vol. xliii, 1887, pp. 190–196. "Die carbone Eiszeit," by Dr. W. Waagen, "Jahrbuch d. k. k. geol. Reichenstalt," Vienna, 1888, vol. xxxvii, Part II, pp. 143–192; reviewed in the "American Geologist," vol. ii, pp. 336–340, November, 1888.

the Permian period ended with disturbance and mountain-building along a somewhat irregular west-to-east course through southern Ireland, Wales, England, northern France, Belgium, Germany, and southern Russia;* and it is to be remarked that this European orographic line lies approximately in the same great circle with the Appalachian ranges, both being included by an arc of ninety degrees. Transverse to this circle the Sinian Mountain system of eastern Asia was formed in the same epoch, stretching from southwest to northeast along the border of the Old World as the Appalachians similarly bound our own continent.† Each of these mountain systems was perhaps much longer than the extent now remaining, and each has been reduced by erosion to only moderate heights; but it is not improbable that their altitude originally was like that of the loftiest ranges of the world, some of which have been formed and the others much uplifted during the last geologic period.

The shortness of the time that has elapsed since the latest glaciation of North America, according to the observations and computations of N. H. Winchell, Andrews, Wright, and Gilbert, shows that this cold epoch was not coincident with the period of eccentricity of the earth's orbit, which is regarded by Croll, Geikie, and Wallace as the primary cause of the Ice age. Eccentricity, therefore, had no share in producing this most recent glaciation, which was more intense and severe, and probably more sudden and brief, than the earlier very cold epoch of the Ice age, as indicated by comparison of the morainic and other drift deposits. Furthermore, it seems probable that the Quaternary Glacial period, including its two or more epochs of glaciation, each subdivided by episodes of temporary retreat and readvance of the ice, besides the principal interglacial epoch of warm or temperate climate, and perhaps complete departure of the North American ice-sheet, was wholly subsequent to the maximum eccentricity which the

* Prestwich's "Geology," vol. i, p. 300.

† "Geological Researches in China, Mongolia, and Japan," by Raphael Pumpelly, "Smithsonian Contributions," vol. xv, 1867, chap. vii. The conclusions reached by Pumpelly concerning this mountain system are fully confirmed by the subsequent grand work of Baron Richthofen on the geology of China.

earth's orbit attained two hundred thousand years ago. Through all the past ages of geology, also, the earth has from time to time passed through similar stages of increased eccentricity, sometimes having a still higher maximum,* which we should expect, in accordance with Croll's theory, to find recorded by deposits of glacial drift intercalated in the Tertiary, Mesozoic, and Palæozoic strata of circumpolar and temperate regions. But the recentness of the Quaternary glaciation, and the general absence of earlier drift formations,† excepting within the Carboniferous and Permian periods, seem to demonstrate that eccentricity has not been the primary cause of glaciation, either with the concurrence of climatic conditions and changes of the course of winds and of oceanic currents such as might attend its slight modifications of the seasons, while the present arrangement and relative heights of land and sea were unchanged, or, as Wallace suggests,‡ with much greater elevation of the areas glaciated, which he thinks to have been necessary, seconding the effects of eccentricity, for the accumulation of ice-sheets. Indeed, we may well doubt that eccentricity has exerted any determining influence in producing unusual severity of cold either during the Quaternary or any former period.

Elevation of broad areas, as half of North America and half of Europe, either synchronously or in alternation, to such heights that their precipitation of moisture throughout the year was nearly all snow, forming gradually ice-sheets of great thickness, seems consistent with the conditions of the earth's crust and interior, which are indicated by the changes in the levels of glaciated countries. A molten magma beneath the solid crust appears, in connection with contraction of the earth

* Croll's "Climate and Time," chap. xix, with plate iv, representing the variations in the eccentricity of the earth's orbit for three millions of years before A. D. 1800, and one million of years after it.

† Nordenskiöld reports that, in sections observed by him in Spitzbergen and Greenland, including all formations from the Silurian to the Tertiary, and occupying in the aggregate, as he estimates, not less extent than a thousand English miles, he has never observed erratic blocks nor any evidence of glacial action.—"Geological Magazine," II, vol. ii, 1875, pp. 525-532, and vol. iii, 1876, p. 266.

‡ "Island Life," chaps. viii, ix, and xxiv.

and the formation of mountain-ranges, to afford an adequate explanation of glaciation. It is probable that the great uplifts which are thus supposed to have caused ice-accumulation were very slow in their progress, and that their effect upon extensive continental areas was so distributed that the maximum changes in slope on their borders would nowhere exceed twenty or thirty feet per mile, while perhaps some portions of the uplifted region would receive no change of slope. And the subsidence beneath the weight of accumulated ice was probably equally slow and similarly distributed, no limited district being greatly changed. Excepting the rare instances where disturbances of mountain-building or extraordinary rising or sinking of mountain-ranges were associated with these movements, the contour of the country, with its valleys, hills, and mountains, has remained in general the same from preglacial time through the Ice age to the present with only changes of slope, small in any limited tract, which in long distances allowed great upheavals and depressions. The elevation of the central part of glaciated areas, with downward slopes on all sides, would favor the outward flow of the ice-sheets and their erosion and transportation of the drift. But mountains and hills jutted upward in ridges and peaks within the moving ice-sheet, as they now stand forth in bold relief above the lowlands; and the ice with its inclosed drift was pushed around and over them, some portions being deflected on either side, and usually a larger part being carried upward across their tops. Katahdin, the White Mountains, the Green Mountains, and the Adirondacks, stood directly in the pathway of the ice outflowing southeastward from the Laurentian highlands. Its thickness in northern New England and northern New York seems to be measured approximately by the elevation of the highest of these summits above the adjoining lowlands, about one mile; but northward the ice-sheet evidently was somewhat deeper upon the valley of the St. Lawrence, and Professor Dana's estimate seems still reliable, that its maximum depth, lying on the water-shed between this valley and Hudson Bay, was probably about two miles.

SUPPLEMENTARY NOTES.

By Warren Upham.

The twenty-one years which have elapsed since the preparation of this chapter have not furnished any facts materially to modify the views here presented. The most important additional discussions of the subject are those of Messrs. Chamberlin and Salisbury advocating an atmospheric theory,* which they state as follows, when treating of the Permian Glacial epoch.

"The increased area of the land, and its increased elevation, give increased contact between the atmosphere and the rocks of the earth susceptible of carbonation and oxidation, as already indicated. As a result, the atmosphere lost carbon dioxide and oxygen at a more rapid rate than in the previous period."

Here, and in other extensive developments of this theory by Chamberlin in the "Journal of Geology," it is definitely shown that the supposed decrease of carbon dioxide, regarded as the chief cause of glaciation, is ascribed to increased altitude of continental areas. In other words, the new theory espoused by Chamberlin and Salisbury, depends in the same way as my epeirogenic theory, called by them the "hypsometric hypothesis," on exceptional continental elevation. Each view recognizes two periods so preëminently characterized by extensive ice-sheets, namely, the Permian and the Pleistocene, that we must believe, from the records of glaciation, that they each had much greater land altitude, for large parts of the continents, than any other period in all the vastly long ages of geologic time. The great epeirogenic elevations preceding and causing both the Permian and Pleistocene ice ages are well emphasized in the foregoing pages; but there we had not learned how the

* See "Geology," vol. ii, pp. 655-677; vol. iii. pp. 424-446; also above p.

ordinary meteorologic conditions of high land elevation were reinforced, in their tendency to produce ice-sheets, by the concomitant depletion of atmospheric carbon dioxide. Now, through the fruitful studies of Arrhenius, Chamberlin, and others, we see how the great altitude of the Continents at these two periods of great areas of long continued glaciation, so very widely separated in time and therefore remarkably unique and exceptional, worked in two ways, not only by the common meteorologic effects, but also by the newly recognized results of depletion of carbon dioxide, to give the marvelous glacial periods thus ending Paleozoic and Cenozoic time.

Further studies will give the proportional effectiveness of these two ways by which great uplifts of the continental areas have induced glaciation. The final theory will rest not less on the sagacious early views of Dana, with their further advocacy by Le Conte and other writers, including Wright and myself, than on the very helpful work of Arrhenius and Chamberlin in their added contribution to explain how the land uplifts accumulated ice-sheets with snowfall all the year upon their vast expanses. Indeed I yet think, that the broad view of the causation of glacial periods as given above was presented truly and vividly, with no more than the proper emphasis on the very exceptional occurrences of only these two periods of general continental glaciation.

Coming next to the great question whether the Pleistocene ice-sheets of North America and Europe were wholly melted away, as is argued by Professor James Geikie and less decidedly by Chamberlin and others, we cannot adduce sure proofs for such conclusions from the central areas of these great ice-sheets on the opposite sides of the Atlantic ocean. The interior of New England and of British America, like the central parts of Sweden and Norway, have not yet revealed such sequence of glacial deposits and intervening fossiliferous beds, of somewhat temperate faunas and floras,

as to give any conclusive evidences of complete departure of the ice-sheets and their subsequent renewal to again spread over nearly all of their former areas. Only in the peripheral parts, broadly speaking, of these two immense ice-fields, are proofs of successive stages of glaciation, divided by old land surfaces and fossil-bearing stratified beds, either of the modified drift or of alluvial, lacustrine, or marine sedimentation.

Minnesota, somewhat far back from our southern limits of the maximum glaciation, has well ascertained proofs of so great recession of the borders of the North American ice-sheet as to uncover the south half of this state, succeeded by renewal of the snowfall and ice accumulation until the borders of our continental ice-sheet again reached southward as far as the Iowan and the Wisconsin drift. The earlier glaciation appears surely to have been of much longer duration than the later Iowan and Wisconsin stages. Thus our Pleistocene Ice age was much diversified and even very complex, yet I would now far more confidently ascribe all our North American drift formations to one prolonged and continuous glacial period, with great fluctuations of the glacial border, especially in the interior of the continent, than to regard our ice age as two-fold or three-fold, in the sense of having its vast ice-sheet wholly melted away, or even nearly so, with ensuing renewal of the snow and ice-fields.

Geologically very rare, an ice age would scarcely be duplicated with so nearly the same limits of ice extension upon half of our continent. The same general conclusion is also, as I think, applicable to the European glaciation. Almost inconceivable geologic duration divided the Permian and Pleistocene Ice ages. In this most recent and geologically short Ice age which has ended, as I surely believe, within the last 10,000 to 5,000 years, at the threshold of the historic period, I cannot think that the stupendous climatic changes implied in the glaciation could permit complete repetition of these continental ice-sheets in America and Europe, in

each area so closely extending to nearly the same maximum limits in the earlier and the later parts of this Glacial period. It is better, until proofs are obtained in the central regions of the drift areas on each continent, to regard their time of glaciation as one and continuous, with much areal oscillation, such as is proverbial of weather, both during the general stages of growth and departure.

My explorations of the Minnesota drift deposits, so far as they appear to require great recession and later reädvance of the snow and ice accumulation, may be cited in the final reports of our state geological survey, the most notable of these observations being as follows, supplementing Prof. N. H. Winchell's observations of an interglacial forest bed in Mower county and other localities of southern Minnesota.*

1. The exceedingly interesting and elsewhere unequaled chains of lakes in Martin county, one of the central counties of our most southern tier, I can explain only by regarding them as proofs of a fully developed interglacial system of drainage running there from north to south, which became afterward ice-enveloped in the Iowan and Wisconsin stages of our Glacial period.†

2. Somewhat the same conclusion seems again enforced by the section of the drift close southwest of New Ulm, in Brown county, about 40 miles north of these chains of lakes.‡

3. In the northern part of Chisago county, on the east side of Minnesota, Rushseba township, in which Rush City is situated, about 50 miles north of St. Paul and Minneapolis, has a considerable tract,§ some 5 or 6 miles long and of nearly as great width, where reddish-modified drift, spread by streams flowing down from the receding northeastern

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* See below p. 605.

† "Geology of Minnesota," vol. i, 1884, pp. 479-485, with the map facing page 472.

‡ Ibid, vol. i, pp. 581-3, with section, and with map facing p. 562.

§ "Geology of Minnesota," vol. ii, 1888, pp. 409-415, 417, 418, the last giving the record of that well, with the map facing page 399.

lobe of the ice-sheet, forming for a time a land surface which bore timber, was subsequently overspread by an ice-lobe whose current was from the northwest to the southeast and east. The overlying yellowish gray till, spread as a continuous and nearly uniform bed only ten to twenty feet thick and forming a nearly level expanse of so much extent, at least 5 miles in diameter, has plentiful limestone fragments from the northwest, being thus in remarkable contrast with the red till deposits lying beneath the gray till in that region, which came from the northeast and therefore has no limestone. A well* on this area encountering peat and decaying fragments of wood in a water-deposited clay beneath the gray till and at the top of the older underlying modified drift gravel and sand, testifies that this was a land surface with peat and forest trees, previous to the very latest glaciation which brought the yellowish gray till.*

4. On the southern part of the area of the Glacial Lake Agassiz, at Barnesville in Clay county, about 190 miles northwest of the Twin Cities (St. Paul and Minneapolis), a well penetrates twelve feet of till, and next beneath, in the bottom of the well, went one foot into quicksand, "containing several branches and trunks of trees, thought to be tamarack, up to eight inches in diameter, lying across the well, which, together with the inflow of water, prevented farther digging." This well is on the till area of the village of Barnesville, about eighty feet below the highest beach of Lake Agassiz, which passes from south to north about three miles east of this village. At the time of my survey of that region and when this volume was published, in 1888, I considered the occurrence of this interglacial bed within the area of the glacial lake as good evidence that the ice-sheet in that interglacial stage was melted back at least so far as to give outflow into Hudson Bay from the Red River Valley, draining off the interglacial forerunner of Lake Agassiz. Subsequent studies and general reasoning lead me, however, now to hold

* See above p. 184.

the different view that probably the earlier interglacial lake in this valley may have even cut its channel of southern outlet, at the site of Brown's Valley, to a lower level than the well in Barnesville, or that the attitude of the land then was unlike what it now has, having then such an ascent from south to north that the Barnesville locality in that interglacial time was above the general surface of the region at Brown's Valley, into which the River Warren, outflowing from Lake Agassiz, cut its deep continuous valley. So I now think that we have there, in the section of this well, only evidence of an ice retreat (that is, a departure of the outer part of the ice-sheet) so far north as to that region, about halfway between the south and north boundaries of this state.* My numerous papers show how, as I think, good forests and other luxuriant vegetation may have flourished near the border of the ice-sheet, accompanying the recession of that border.

The questions are sure to be asked: Why is the boundary of the glaciated region in the United States so irregular? What was the cause of its withdrawing so far north in western New York, and of its sudden bend to the south in eastern Ohio, and of its lobe-like projections in southeastern Indiana and southern Illinois? And what was the cause, at a later stage, of the lobate contour of the moraines west of Lake Michigan in Wisconsin, Iowa, Minnesota, and Dakota? These questions we can only answer by saying that the distance to which the great American ice-sheet penetrated the southern latitudes was evidently not dependent, to any great extent, upon the elevation of the land over which it was compelled to move. The ice did not uniformly move farther south where there was a depression of the land, and the boundary does not ordinarily retreat to the north on account of the higher elevations opposing its progress. South of New England the

* *Geology of Minnesota*, vol. ii, pp. 661-2, and 668; with the map facing p. 656.

glacial front was at the sea-level, and the ocean itself may have kept it from advancing farther. In Pennsylvania the boundary-line crosses the Alleghany Mountains diagonally, being nearly as high on Pocono Mountain, in the eastern part of the State (about two thousand feet), as in the southwestern part of New York, where it is sixty or seventy miles farther north. In Ohio the highest portion of the State is in Logan county, almost directly north of Ripley, in Brown county, the most southern point reached in that State. The unglaciated portion in southern Indiana, projecting about seventy miles northward into the glaciated region, is indeed somewhat higher than the land on either side, but nowhere is its elevation greater than that of the larger portion of Ohio. The farthest extension of the ice in Illinois is closely coincident with the trough of the Mississippi Valley, and westward of the Mississippi River the edge of the ice withdrew farther and farther north pretty nearly in proportion to the increasing elevation of the country, until, at Sim's Station, in the vicinity of Bismarck, Dakota, it is nineteen hundred and sixty feet above tide, and continues thence to ascend northward to a height of three or four thousand feet in the upper valley of the Saskatchewan.

There is, thus, a general conformity in its southern extension to the valley of the Mississippi. The ice of the Glacial period as a whole did, indeed, move down that great valley, and its most southern point is in the middle of it, where it it is not more than five hundred feet above the sea; but it is evident that the total width of the southern portion of this ice-sheet is so great, and the slope itself so slight, that this depression could not have been the main cause of the great extension to the south in Illinois. The width of the glaciated area from southern Ohio to eastern Kansas, on the thirty-ninth parallel, not far from the extreme limit of glaciation, is nearly a thousand miles. The cause, therefore, of the lobate character of the southern boundary must, in all probability, be sought in the irregular areas of excessive snow-fall existing to the north during the advance and continuance of

the Glacial period. From a glance at the map it would seem, therefore, that the greatest area of snow-fall was somewhere in the vicinity of Lake Superior, and that a secondary area of large snow-fall was in the vicinity of Labrador; for the southern boundary of the glaciated region consists essentially of the arcs of two circles whose centers would fall within the areas indicated.

In speaking of these two areas as centers of radiation for the glaciers of the great Ice age in North America, it is not affirmed that the movement received no impulse from still farther north. It is not improbable that the upper portion of Baffin Bay was filled and crossed by the glaciers still lingering over the continental area of Greenland, and that this Greenland ice aided in the movement which covered the northern part of the United States with its icy mantle. But it was probably by reaction rather than by direct action that aid came from that quarter. The accumulations to the north prevented an outflow in that direction, and so compelled a southerly movement from the vicinity of the Laurentian highlands. It is not, however, probable that any Greenland ice ever reached the United States. None of the bowlders so common in the United States are, so far as known, more than a few hundred miles distant from their parent ledges. There was doubtless all the while an ice-stream down Baffin Bay toward the Atlantic Ocean, with a movement into it from both sides. But even if this were not the case, the areas south of Hudson Bay and in Labrador would still be the predominant influence in determining the southern outline of the glacial boundary. The snow that piled up from year to year over those centers would be compelled to move off in the lines of least resistance. Now, ice can be an obstruction to other ice as well as to water; and what the Greenland glacier probably did was to close up the upper portion of Baffin Bay, so that the excess of snow-fall over the subcenter referred to as north of Lake Superior could not move off to the northeast, but was compelled to spend all its force in a southerly movement. It is evident also that

every subcenter where the snow-fall was larger than the average would, to some extent, make its influence felt upon the shape of the margin.

Here is a field for the mathematician. When the properties of ice are more fully understood from experimental investigations, and the laws of its fluidity brought under mathematical formulæ, it will doubtless be possible, from a study of the contour of the glacial boundary, to calculate the position of all the principal areas of largest precipitation during the Glacial period.

Those remarkable lobe-like projections in southern Ohio and Indiana, for example, indicate subcenters of accumulated ice not far back from the margin. The still more remarkable prolongation of the loops in the kettle-moraine in Wisconsin, and its extension through the States farther west, point, as President Chamberlin sagaciously and correctly supposes, not merely to greater snow-fall over the regions from which the ice-movement radiated, but to the conservative influence of the deeper valleys and depressions to the north, which were filled with ice. These loops of the kettle-moraine sustain a remarkable relation to the valley of Green Bay, and to the northeast and southwest axis of Lake Superior, while the ice-lobe which occupied the valley of the Minnesota and extended to the center of Iowa is evidently related to the great valley of the Red River of the North. It is not improbable that the depth of ice in such a depression as Lake Superior would, by its very thickness, tend for a long time to increase the snow-fall over its own area, and in other ways to resist the antagonistic agencies which were gradually driving the ice-front back to the north. The driftless area of southwestern Wisconsin is situated just where it escapes these several ice-movements dominated by the depths of Lake Michigan and Lake Superior, and it is to this day—as Professor Dana has pointed out—a region of light precipitation.

If this discussion of the cause of the Glacial period seems unsatisfactory, the justification is that the present

knowledge of the whole subject is in an extremely unsatisfactory condition; and in this, as in other things, the first requisite of progress is to squarely face the extent of our ignorance upon the question. The causes with which the glacialist deals are extremely complicated, and yet they are of such a nature as to invite investigation, and to hold out the hope of increasing success in mastering the problem. There is opportunity yet for some Newton or Darwin to come into the field and discover a clew with which successfully to solve the complicated problem which has so far baffled us. To the genuine investigator it is a source of inspiration rather than of depression to have such an untrodden field before him.

Conclusion.—Geology is pre-eminently a terrestrial science, and there is danger of a misdirection of effort when the geologist forms an alliance with the astronomer. Astronomical data are so largely theoretical, and the quantities which the astronomer multiplies are often so nearly infinitesimal, that quantitative error is in peculiar danger of becoming enormous in large calculations. Hence, we can not count it altogether an advantage that astronomical speculation has been so rife during the past few years in determining the causes and the chronology of the Glacial period.

Of the various cosmical theories to account for the Glacial period, that of Mr. Croll is by far the most plausible and interesting. It must be admitted that his data concerning the various distances at which the earth is found from the sun during the winters of different periods, and concerning the periodical variations in the length of the winters, rest upon well-ascertained facts. It is no doubt true that about one hundred thousand years ago the winters were at times several days longer than now, and the northern hemisphere was receiving daily considerably less heat than now, since it was several millions of miles farther away from the sun.

But the distribution of the earth's heat by winds and oceanic currents is a subject concerning which much less is known. The phenomena presented in a hot-house are puz-

zling. The heat of the sun goes through the glass, but can not readily get out again. It is well known, also, that a slight increase of moisture in the atmosphere, or a slight film of cloud over the sky, prevents a frost. The real problem lies, therefore, in the meteorological field. Now, during Mr. Croll's "aphelion" winters, the summers are in "perihelion," and the summer heat in this hemisphere while in perihelion is more intense than at other times. In fact, the earth receives at all times the same absolute amount of heat from year to year. Thus, we can not avoid the conclusion that the predominant influence in climate may consist in the power of moisture-laden atmosphere to retain and transport the heat, thus determining its distribution. As a matter of fact, we find that the equator is not so hot as theoretically it should be, and the arctic regions are by no means so cold as, on Croll's theory, they ought to be. The difference between the mean temperature on the equator and that at the coldest point on the sixty-seventh parallel is really only about 75° Fahr.; whereas, if the temperature at these points were proportionate to the amount of heat received from the sun, the difference would be 172°. Such facts as these lead meteorologists to regard Mr. Croll's theory with much less favor than formerly.

But the glacialist is not so much concerned to know the ultimate cause of the Glacial period as he is to collect the facts which characterize the period. The truth is, that the meteorological forces of Nature are so powerful and complex that there is an embarrassment of riches in the field of glacial theory. It is easy to see that a slight increase of snowfall over the Alps would cause a permanent enlargement of all the glaciers of Switzerland, and threaten every interest of that republic, and perhaps of central Europe; for the ultimate effects of a climatic disturbance in one such center can not well be estimated.

Much light upon the condition of things during the Glacial period in America must yet come from a careful study of the lobate contour of the terminal moraines. The shapes

of these moraines, coupled with what may yet be learned concerning the nature of ice and concerning the shifting course of the atmospheric currents, will, in all probability, eventually furnish the data for the solution of the question of the true cause of the Glacial period. A fair field here invites the active and prolonged attention of some future meteorological Darwin or Newton, and promises immortality such as they have attained.

CHAPTER XX.

THE DATE OF THE GLACIAL PERIOD.

Two causes have combined in recent years to favor erroneous calculations concerning glacial chronology. Of these, the first has been the almost unquestioned acceptance of the astronomical theory subjected to examination in the preceding chapter. If Mr. Croll's theory of the cause of the Glacial epoch is correct, then we should no longer speak of *an* ice age, but of a *succession* of such ages, whose dates could be readily determined from a table showing the periods of highest eccentricity in the earth's orbit. According to this table, the modern period most favorable to the production of a glacial epoch began about two hundred and forty thousand years ago and ended about seventy thousand years ago. The whole intervening time was one of high eccentricity, when, during the recurring intervals in which the winters occurred at aphelion, the excess of winter over summer ranged from fourteen to twenty-six days, and the intensity of the heat received from the sun during those aphelion winters was ten per cent less than at the present time. During the time intervening between seventy thousand and two hundred and forty thousand years ago, there occurred, therefore, according to this theory, a succession of glacial and interglacial periods in which geologists and archæologists are invited to distribute their remarkable discoveries concerning glacial man. Undue confidence in this theory has had no small influence in diverting attention from the more legitimate lines of investigation.

A second source of error has been an incorrect interpre-

tation of Lyell's principle of uniformity in Nature's operations. This has led to an exaggerated estimate of everything pertaining to geological time. There is a prevalent popular impression that all geological events happened a great while ago. This impression arises largely from the imperfect apprehension of the extent to which changes are now going on in the world. In reality, however, Lyell's greatest service consisted in quickening our conception of the *instability* of the present condition of things, and of the intensity of present natural forces. He riveted the attention of his readers upon the cumulative effect of such earthquakes as are now of daily occurrence, and occasionally of enormous influence, and continually reminded them of the frequency and intensity with which new volcanoes are now from time to time bursting forth. *Continuity*, therefore, rather than uniformity, is the word which most properly expresses the principle underlying the theories of this great geologist. A perusal of his works makes it evident that *evolution*, and not *dull repetition*, characterizes the processes of Nature. There is therefore really nothing in Lyell's working principle to raise any antecedent presumption in favor of an extreme antiquity for the Glacial period.

On the contrary, the present tendency, both among astronomers and geologists, is to diminish estimates of geological time in almost every period. The hundreds of millions of years claimed, not long ago, as necessary for the deposition and metamorphism of the geological strata, and for the elevating and eroding forces to produce the present contour of the earth's surface, have on geological evidence been reduced to much more moderate limits. Thirty million years is now shown to be ample for the deposition, by forces still in operation, of all the sedimentary strata of which we have knowledge. At the same time the astronomers affirm that life can not have existed on the earth earlier than twelve million or fifteen million years ago.* Before that period

* See Newcomb's "Popular Astronomy," pp. 513–519.

the radiation of the sun's heat was so intense that life must have been impossible upon our globe.

But he who pauses to reflect upon how long a period one million years is, and takes the pains to multiply the annual changes of the present time by that number, will not feel cramped by the limits which astronomers are now setting to geological time. In this general shortening of our conception of geological periods, the evolutionists also find no small relief in the more moderate estimates made concerning the date of the close of the Glacial period; for it is very clear that the changes in species since the great Ice age are trifling. The flora and fauna of the world during the Glacial period were essentially the same as those of the present time. Even man is believed to have been an inhabitant of America, as well as of Europe, before the ice had withdrawn from the head-waters of the Delaware River, and from the mountains of Scotland and the north of England. If these changes in the organic world have been so slight since the Glacial epoch, it follows that, the further back that period is placed in time, the greater are the difficulties of the evolutionists. The more the evolutionists are limited in time by the astronomers, the more do they need a rapid rate of change as the basis of their calculations. If, therefore, the Glacial period should prove to have ended only ten thousand years ago instead of seventy thousand, the Darwinian would be relieved from no small embarrassment. Thus, so far as there is likely to be any *odium theologicum* in the case, the desire to support a short biblical chronology and the counter-desire to discredit Darwinism, and *vice versa*, may be left to counteract each other.

In view of the doubt expressed in the preceding chapter concerning Mr. Croll's theory, it does not seem proper for geologists to rest satisfied with mere astronomical calculations respecting glacial chronology. We may, therefore, be permitted to turn to the more congenial task of considering the direct geological evidence bearing on the question. In this field there are three classes of facts to which we can

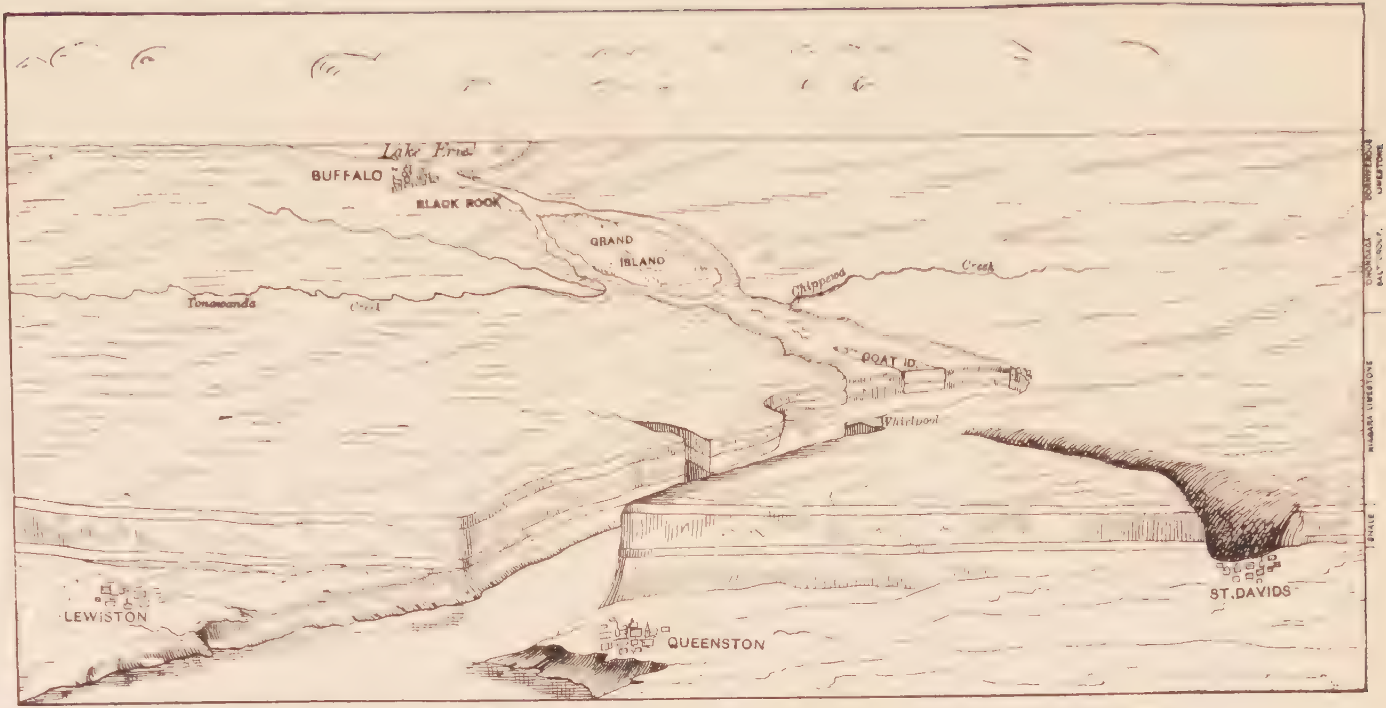

FIG. 132.—Bird's-eye view of Niagara River. (Pohlman.) (By courtesy of American Institute of Mining Engineers.)

confidently look for light: 1. The amount of erosion and disintegration which has occurred since the Glacial period. 2. The extent to which lakes and kettle-holes have been filled with sediment. 3. The apparent freshness of organic remains in glacial deposits.

Beginning with the extent of erosion which has taken place since the withdrawal of the ice, our attention is, naturally enough, directed first to the gorge below the Falls of Niagara. How this comes to be a glacial chronometer has already been seen.* The old outlet of Lake Erie, which must have existed as the result of preglacial erosion, was filled up during the great Ice age, and the Niagara River is the outlet of the pond thus created. Originally the water plunged over the escarpment at Queenston, about seven miles below the present cataract. This escarpment is formed by an outcrop of a thick deposit of Niagara limestone, the summit of which is about three hundred feet above the level of Lake Ontario. This is underlaid by a softer rock, which is more rapidly disintegrated than the upper strata; hence the upper strata always project beyond the lower, and everything favors the continuance of the cataract at the head of the gorge as it wears back. The problem is to determine how long the Niagara River has been in wearing out the gorge between Queenston and the present cataract. The solution of that problem will furnish an answer to the other question, How long has it been since the ice-barrier across the valley of the Mohawk was removed, so that the dammed-up waters of Lake Ontario and Lake Erie would subside sufficiently to permit the formation of the cataract at Queenston and the commencement of erosion in the present gorge? The problem is comparatively simple, and its bearing upon the date of the Glacial period is clear.

The Falls of Niagara have receded about seven miles. The conditions have been from the first so nearly uniform that the present rate of erosion can not differ largely from

* See chapter xii, p. 303 *et seq.*

the average rate. There is some evidence that a part of the work above the Whirlpool had been done by a local stream

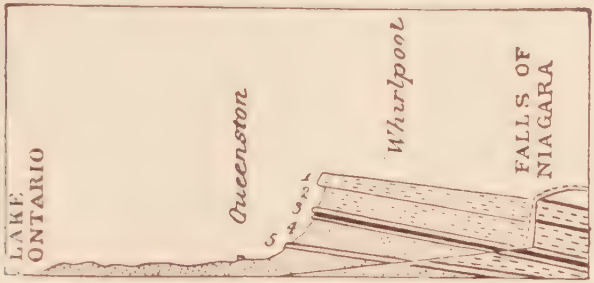

FIG. 133.—Section of strata along the Niagara gorge from the falls to the lake. 1, 3, strata of hard rock; 2, 4, of soft rock.

which formerly passed from the Whirlpool westward to St. Davids, since there is no doubt of the existence of a filled-up preglacial channel running from the Whirlpool to St. Davids. But the evidence that this channel extended above the Whirlpool toward the present cataract is so imperfect that we must leave it out of the question, and take the whole length of the gorge from Queenston to Niagara as our dividend. The problem remaining is to find the rate of recession, and this will serve as a divisor.

The comparative youth of the Niagara gorge is evident from the present condition of its mouth at Queenston. This is narrow, and its walls abrupt; but it is well known that, by the inevitable action of natural forces, the mouth of a river-gorge must become, in process of time, very much enlarged, since from the beginning its sides have been exposed to the eroding action of the elements and to the undermining action of the river. In the unglaciated region the mouths of such gorges are universally wide and V-shaped, and the banks much obscured at the bottom by the accumulation of *débris*. In this respect the mouth of the present gorge at Queenston is in striking contrast with that of the old gorge which opened at St. Davids. As will be seen by reference to the map, this, though narrower where it left the Whirlpool than the present main gorge below the Whirl-

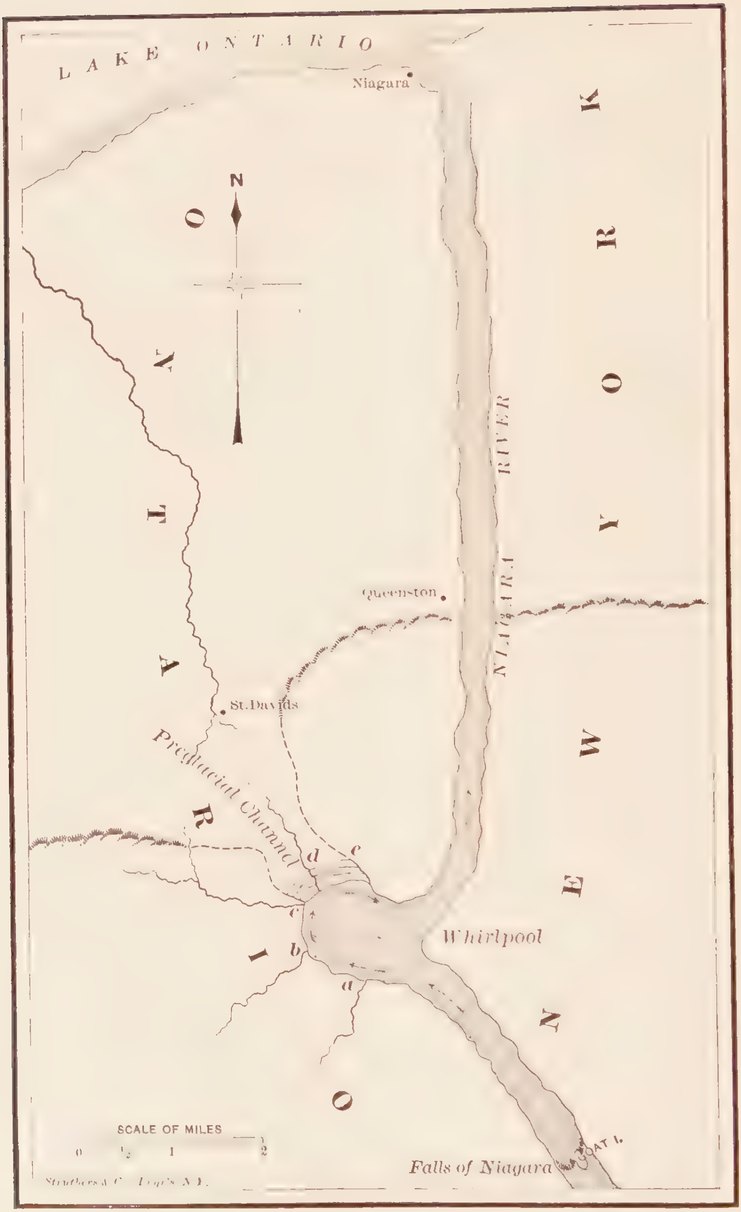

FIG. 134.—Map of the Niagara River below the falls, showing the buried channel from the whirlpool to St. Davids. Small streams *a*, *b*, *c*, fall into the main gorge over a rocky escarpment. No rock appears in the channel at *d*, but the rocky escarpment reappears at *e*.

pond and not over half as long, is still at its mouth by St. Davids several times as wide as that of the present Niagara gorge at Queenston.

Coming to the main question, and taking the whole of the gorge from Queenston to the present cataract as the work done by the Niagara River since the ice-barrier in the valley of the Mohawk gave way, the problem is to find the rate of recession. Until very recently the estimates of this rate have been scarcely more than mere guesses. The eminent French glacialist Desor thought it could not have been greater than one foot in a century, which would place the beginning back 3,500,000 years. In 1841 Sir Charles Lyell and Professor James Hall examined the gorge together; and Sir Charles, in his lectures in Boston before the Lowell Institute soon after, estimated that the maximum rate of recession could not be greater than one foot a year, which would fix the minimum date of its beginning at about thirty-five thousand years ago. On the contrary, all the guides of that period who had observed the falls for many years, were confident that the rate of recession was as much as two feet a year;* while Mr. Bakewell, an eminent English geologist, who had given much personal study to the question, estimated that, for the forty years previous to 1830, the rate of recession had been about three feet a year. Mr. Bakewell's son carefully reviewed the phenomena again in 1846, in 1851, and in 1856, and found no occasion to revise his father's estimate.†

To furnish the basis for more accurate calculations, Professor James Hall had a map of the falls made in 1842, from a trigonometrical survey, so that there should be a fixed standard for future comparison. Within the past few years, accurate surveys have again been made, both by the geologists of the State of New York, and by members of the United States Coast Survey. In 1886 the American Association for the Advancement of Science held its annual meeting

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* Lyell's "Travels in America" (first series), vol. i, p. 27.

† "American Journal of Science," vol. lxxiii, 1857, pp. 87, 93.

at Buffalo and great interest was naturally centered upon this question of the rate of the recession of the falls. Mr. G. K. Gilbert, of the United States Geological Survey, whose authority is unsurpassed on such subjects, gave it as his conclusion that the "maximum length of time since the birth of the falls, by the separation of the lakes, is only seven thousand years, and that even this small measure may need significant reduction." At the same time Mr. R. S. Woodward,* of Washington, made a new survey, and gives the results definitely as follows: The length of the front of the Horseshoe Fall is twenty-three hundred feet. Between 1842 and 1875 four and a quarter acres of rock were worn away by the recession of the falls. Between 1875 and 1886 a little over one acre and a third disappeared in a similar manner, making in all, from 1842 to 1886, about five and a half acres removed.

Subsequent surveys have amply supported these conclusions. From the survey made in 1905, by Mr. Carvel Hall, state engineer of New York, it appears that the recession of the Horseshoe Fall (which is where the principal volume of water descends) during the sixty-three years between 1842 and 1905 was 333 feet, or at the rate of 5.3 feet per annum

The foregoing estimates concerning the recession of the Niagara gorge assume a uniform rate, and that all the work has been done since the glacial period. As to the first of these assumptions, Dr. Julius Pohlman,† of Buffalo, adduces some evidence to show that the present course of the Niagara from the Whirlpool to Queenston follows an old line of drainage, in which a small stream had eroded a shallow valley previous to the ice period, and thus, by reducing the thickness of the upper layer of hard limestone along its course, had greatly facilitated the work of recession, when the whole torrent of Niagara began to pour over the escarpment. Dr. Pohlman has also greatly increased our conception of the work already done before the Glacial period by the stream which had its exit from the Whirlpool to St. Davids. This

* Report in "Science," September 3, 1886.

† "Transactions of the Amer. Institute of Mining Engineers," 1888.

FIG. 135.—Map showing the recession of the Horseshoe Fall since 1842, as by surveys mentioned in the text. (Pohlman.) (By the courtesy of the American Institute of Mining Engineers.)

stream, composed of the waters of the Tonawanda and Chippewa Creeks, was of considerable extent, and by its action had doubtless predetermined the course of the present river above the Whirlpool, and may actually have worn a considerable part of the present gorge above the Whirlpool.

Another element of uncertainty, which has led Mr. Gilbert and others to retract their former views, or at least to hold them in suspense, relates to the variations of the water supply since the beginning of the erosion.

It should, however, be noted that the erosion at Niagara began long before the close of the Glacial period, namely when the ice had melted off from the Mohawk Valley so as to permit the drainage to take that course to the Hudson, and lower the level of the existing glacial lake to that of the col at Rome, N. Y. This would permit erosion to begin at the mouth of the Niagara gorge, long before the ice had retreated from the lower St. Lawrence Valley and from Canada in general.

A most interesting state of things respecting the variations of the water supply at Niagara comes to light in connection with the differential northerly depression of land during the Glacial period, and its re-elevation after the disappearance of the ice. From the fact that there was a northerly depression of 600 feet at Montreal, and presumably as much in the northern basin of the Great Lakes, it follows that upon the melting off of the ice from the Ottawa Valley, and from the water parting between it and Lake Huron, the drainage might for the most part be diverted in that direction, leaving the Niagara with only that supply of water which would be furnished by the local basin about the east end of Lake Erie. In 1892, I was so fortunate as to find clear evidence of this outlet leading across from Lake Nippissing, past the town of North Bay, into the Mattawa River and thence into Ottawa at the town of Mattawan. The col at North Bay is less than 100 feet above the present level of Lake Huron, while the evi-

dences of a post-glacial flow of water in enormous quantity are perfectly clear. At Mattawan there is an enormous delta of bowlders where the valley of the Mattawa joins that of the Ottawa. Many of the bowlders are several feet in diameter, and they are all waterworn. Moreover, the bowldery delta has been pushed out into the Ottawa Valley so as to dam the river and create a deep lake-like expansion above and a long series of rapids below. In confirmation of the theory that there was a flow of water through this channel for a considerable time Mr. Taylor found miniature pot-holes worn in some of the large bowlders of the delta terrace at Mattawan.

Of course while the drainage of the Upper Great Lakes was diverted around to the St. Lawrence by way of the Ottawa Valley, the recession of the Niagara gorge was practically at a standstill. It is important therefore to ascertain how long a time this continued. Calculations upon this point will largely depend upon the question of how rapidly the post-glacial re-elevation of the region went on. Happily we have much evidence upon this point, all of which indicates a rapid rate as compared with that which is now going on.

The most important evidence comes from Dr. Upham's study of the shore lines of the glacial Lake Agassiz which spread over the valley of the Red River of the North (see page 401). This temporary lake covered more than 100,000 square miles and its shore lines are easily traced for hundreds of miles, like railroad embankments, across the prairie country of that region. There are several series of these shore lines, at successively higher levels. But at the head of the valley where the outlet was through Big Stone and Traverse lakes into the valley of the Minnesota River, the beaches are approximately at the same level. On proceeding northward, however, while the lower beach remains nearly horizontal, the upper one rises until in latitude 51° 52,′ 200 miles north of the international boundary, it is 400 feet above the lower shore line. Thus it appears that during the existence of this

FIG. 136—Exposure of Niagara shale in Niagara gorge. (Photo by Dutton).

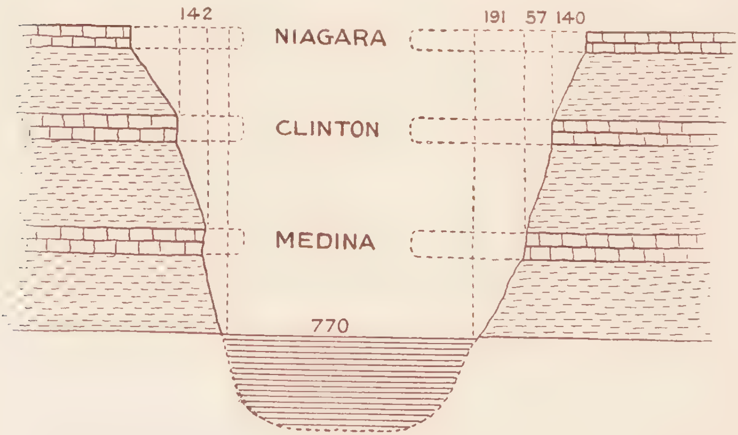

FIG. 137—Diagram showing small amount of actual enlargement of the mouth of Niagara Gorge at Lewiston.

lake there was a rise of 400 feet in the northern part while there was a rise of but a few feet at the southern end.

These facts give us a chance to estimate the rate of this differential rise in the land lying north of the glacial border which has been going on up to the present time, and thus furnishes data from which to calculate the length of time during which the depression at North Bay was sufficient to divert the water of the Upper Great Lakes from Niagara. From the data collected by Dr. Upham during his investigations of Lake Agassiz he concludes that its entire existence could not have been more than 2,000 years and probably was not more than 1,000 years.

The facts upon which Dr. Upham relies, are: 1. The small size of the deltas deposited on the margin of the lake by the great rivers entering from the west; 2. The small size of the ridges themselves; 3. The limited extent of the dunes about the southern end of the lake.

1. The most important rivers which formed deltas in the lake are the Cheyenne, the Assiniboine and the Saskatchewan, which all come in from the region to the westward which was free from ice during the greater part of the time of the existence of the lake. The gradient of these streams is rapid, and the supply of sand and gravel within their reach is abundant. Yet their delta deposits at the level of the beaches is small, and entirely inconsistent with the continuance of the lake for more than 1,000 or at most 2,000 years.

2. The shore lines, or beaches, are very much smaller than those around Lake Erie, which, as we elsewhere show, could not have been more than 2,000 to 3,000 years in forming.

3. The dunes at the south end are not over one-tenth the size of those at the south end of Lake Michigan, which demonstrably were not over 10,000 to 15,000 years in forming. In explanation of this point it is necessary to call attention to the facts concerning the dunes south of Lake Michigan. These are very prominent features along all the railroads

FIG. 138—Photograph looking north-west towards St. Davids showing the excessive enlargement of the mouth of the preglacial channel.

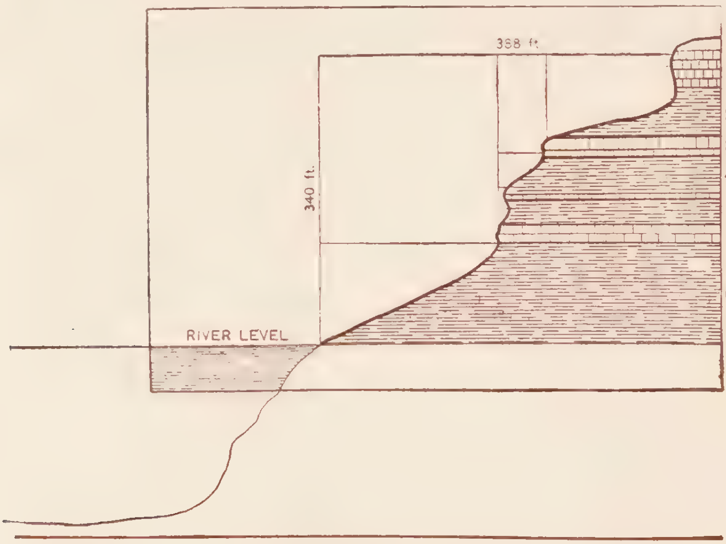

FIG. 139—Section, drawn to equal vertical and horizontal scale, showing enlargement of Niagara gorge on the east side at its mouth at Lewiston: 1, Niagara limestone, 20 to 30 feet; 2, Niagara shale, 70 feet; 3, Clinton limestone, 20 to 30 feet; 4, Clinton and Medina shale, 70 feet; 5, Quartzose Medina sandstone, 20 to 30 feet; 6, softer Medina sandstone, 120 feet above water level.

entering Chicago from the east, but they are limited in extent, and are in process of formation at the present time, the rate of which can be approximately calculated. Lake Michigan is now a closed body of water at the south end, and it is eating into its western banks and bluffs at a rapid rate, the shelf eroded by the waves since the departure of ice from its central depths being about seven miles wide. The shingle, gravel and sand derived from this erosion of the banks is carried along the west shore southward past Chicago to the south end of

FIG. 140—Hypothetic hydrography of the Great Lakes at a date after the melting of the great glacier from the St. Lawrence Valley.

the lake, where it is taken up by the wind and blown outward to form the dunes which are now so prominent a feature in the landscape. It has been important for various reasons to learn how fast the sand is being carried past the Chicago front, so that engineers have made very careful estimates. On comparing the rate at which the material is being carried past Chicago, with the total amount of sand contained in the dunes at the south end of the lake, it appears that the process cannot have been going on more than 10,000 years.

Now, since Dr. Upham estimates that the dunes at the south end of glacial Lake Agassiz are not over one-tenth the

size of those south of Lake Michigan, those on Lake Agassiz would have been formed in about 1,000 years. Hence this differential northerly elevation of land over the basin of Lake Agassiz to the extent of 400 feet must have taken place within that limited period. Such being the ascertained rate of elevation in the Red River Valley, it is altogether probable that the rise in the land at North Bay would not occupy a much longer period, for the conditions with respect to the glacial ice and its recession are nearly alike in both regions. In addition to this evidence adduced by Dr. Upham, I had long before called attention to the small amount of erosion which had taken place in the delta at Mattawan since the glacial outlet there had been closed.

Another independent line of evidence indicating the brevity of the past life of the Niagara gorge is drawn from a study of its width at the mouth. In 1898 and 1899 I was deputed by the New York Central Railroad to study the lower part of the eastern side of the gorge, to shed what light I could upon the stability of the conditions surrounding the road bed built along the face of the gorge. Every facility for examination and measurement was granted me. Briefly, the results were as follows: the width of the river at the mouth of the gorge is 770 feet, which is practically the original width of the gorge, for the *débris* falling down has prevented the stream from enlarging its channel at the base of the cliff.

Assuming that the cliff was originally perpendicular, measurements showed that the strata at the summit had receded on the east side only to the extent of 388 feet, making the total width of the top of the gorge at the mouth 1,553 feet, on the supposition that the west side had been worn away as fast as the east side had been. But various irregularities prevented as accurate measurements on that side. Now this subaërial erosion of 388 feet from the top of the gorge on one side indicates the removal of an inverted section of the face of the gorge, with a base of 388 feet and a height of 340 feet,

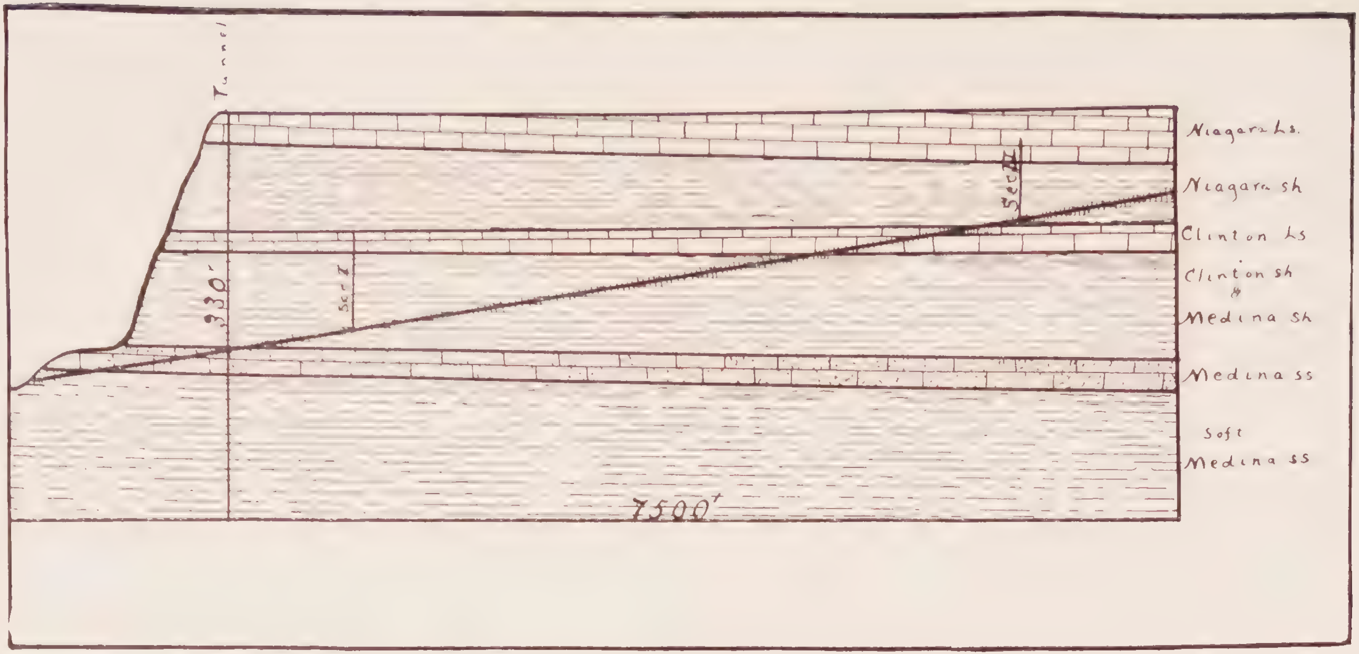

Plate X—Section on east side of Niagara Gorge, at its mouth; showing course of New York Central Railroad.

the height of the cliff at this point. If the subaërial erosion of the face of the gorge proceeded at the rate of one-quarter of an inch per annum, the material would have been removed in less than 10,000 years. That this rate is not excessive was shown both from the vast amount of *débris* that is now annually precipitated upon the railroad track, and from actual measurements of the extent to which the hard strata of limestone had been undermined since the track was laid, in 1854, when it was found that the underlying Clinton and Niagara shales had worn away more than three inches a year, leaving the harder strata to project from thirteen to fourteen feet. As illustrating the rapidity of erosion from the sides of the gorge it is in point to remark that in 1898 there fell off at one time from the face of the cliff on the east side of the Whirlpool, 100,000 tons of rock, whereas the amount which we have supposed to fall away annually from the one mile and a half measured by us is only 1,237 tons. From these facts it is evident at once that the erosive agencies tending to give a V-shape to the mouth of the gorge could not have been in operation much more than 10,000 years. To suppose they had been at work for 30,000 or 40,000 years, as many still try to do, involves an absurdly low rate of activity on the part of the forces which have been constantly at work.

Something more also needs to be said about the significance of the preglacial channel leading from the Whirlpool to St. Davids. In the first place it should be noted that the mouth of this gorge is very wide, being in fact nearly a mile in width, thus indicating great age. In the second place, the depth of the Whirlpool (150 feet), and the width of the head of the St. Davids gorge (fully twice that of the Niagara gorge immediately above and below), point to an extreme age. It seems altogether probable, indeed almost demonstrable, that the St. Davids' gorge had been worn back by a small stream formed by the junction of two streams, one coming along the line of the present gorge through the Whirlpool Rapids, and the

other coming from the north from a small water shed bounded by the escarpment at Queenston. As the gorge both above and below the Whirlpool is for some distance not more than one-half the average width, it is probable that through these spaces these small streams had worn in preglacial times narrow gorges leading to the Whirlpool which had only to be cleared of their glacial *débris* and somewhat enlarged by the present stream when the cataract had receded to that point. This would account both for the narrowness and the shallowness of the gorge at these places. Whereas the water at the Whirlpool is 150 feet deep and still more than that for two miles below the Falls, it is only 35 feet deep in the Whirlpool Rapids. Furthermore, at Fosters Flats, one mile below the Whirlpool there is a projecting shelf extending into the gorge from the western side nearly half its width, but into its upper end on the side next to the main cliff there is the head of an old narrow gorge opening up stream. This can hardly be anything else than a remnant of the gorge supposed to have been formed by a small northerly stream which found an outlet through the Whirlpool.

We are bound to state, however, that Dr. Spencer maintains that the St. Davids outlet was not worn down to the level of the present Whirlpool, and so is only a remnant of erosion in some preceding era. But it is to be observed that Dr. Spencer's borings to determine the depth of the glacial filling in the St. Davids gorge, were considerably one side of the center, while the measurement nearest the center was abandoned before penetrating the rock below. The great age of the gorge would imply a fully formed V-shape for it, which would make the depth of the glacial filling to be small near the sides. There is, therefore, no valid reason to doubt that the St. Davids preglacial outlet was complete from the Whirlpool at a depth equal to that of the present Niagara gorge.

In view of all these considerations it seems evident that a

considerable portion of the erosion of the Niagara gorge, both above and below the Whirlpool, had been accomplished before the glacial period, so that all the present stream had to do was to clear of its unconsolidated till the portions of the preglacial gorge which it occupied, and somewhat widen the channel.

For future reference, if for nothing else, it is worth while to introduce at this point a portion of our detailed study upon the rate at which lateral erosion is proceeding through atmospheric influences alone along the face of this gorge.

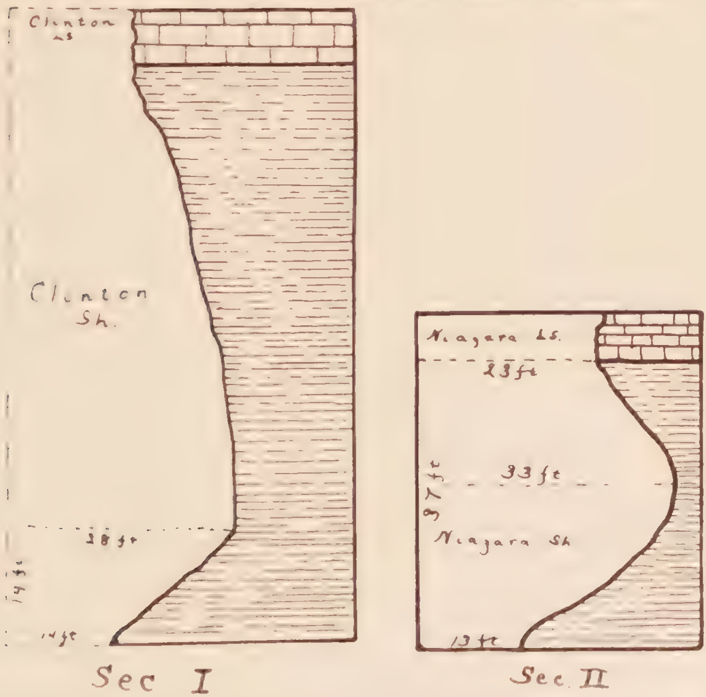

FIG. 141—Sections showing the actuol rate of erosion along the sides of the Niagara Gorge.

Section I was made 860 feet south of the tunnel at the north end of the gorge, and the measurements were taken from the outer rail of the track at points where a perpendicular excava-

tion in the Clinton Shale had been made fifty-five years before. The average of fifteen measurements made at twenty foot intervals, showed that at the line of greatest erosion fourteen feet of the Clinton Shale had fallen away during that period; giving a rate of three inches a year.

Section II was made 6.317 feet from the tunnel in what was a perpendicular excavation in the Niagara Shale fifty-five years before. The average amount of greatest erosion along this exposure was obtained by eleven measurements throughout a distance of 1.185 feet, and proved to be fourteen and eight tenths feet, or three and one quarter inches per year.

From these measurements it appears that the rate at which the Clinton and Niagara shales crumble away over the whole surface, through atmospheric agencies alone where unprotected, is one and a half inches per year.

The question as to how much protection has been afforded by the talus and the growth of vegetation cannot be definitely answered, but as our photograph on p. 544 shows the Niagara shale has not been protected to any extent by a talus, and but slightly by vegetation. It therefore seems entirely within the bounds of probability that the erosion of the Niagara Shale at the mouth of the gorge has proceeded at one-seventh the rate at the exposures measured, which is about one quarter of an inch per year, or one foot in forty-eight years, which is the rate necessary to accomplish the whole amount in 10,000 years.

A second typical place for the study of the recession of post-glacial waterfalls is presented in the gorge of the Mississippi River below the Falls of St. Anthony at Minneapolis. The problem here presented has been carefully studied by Professor N. H. Winchell as follows.*

From the Falls of St. Anthony to Fort Snelling the gorge between the rock-bluffs is somewhat less than a quarter of a

* "Geology of Minnesota," vol. ii, pp. 313–316, 340, 341.

mile in width, and the rock has a freshly broken appearance, the large fragments thrown down by the action of the water on the easily crumbled sand-rock, as the falls have receded, still existing in the talus along the bluffs. Throughout this distance (about eight miles) the strata are horizontal, the thickness of the drift-sheet overlying them nearly uniform, and all other conditions, so far as they can be seen, that would affect the rate of recession, seem to have exerted an unvarying influence. The inference is inevitable that the rate of recession has been practically uniform between the two points named. There is an aspect of age, and long weathering, presented by the rock in the bluffs of the Mississippi below Fort Snelling. It has a deeply changed color, a light-yellow, oxidized exterior, which marks all old bluffs. The blue color is found at greater depths from the surface than it is in the rock of the bluffs above Fort Snelling. This stained condition also pervades the lime-rock at the mouth of Bassett's Creek and at the quarries in the ancient river-bluffs near the mouth of Shingle Creek, on both sides of the river. Another notable difference between the bluffs above Fort Snelling and those below consists in the absence of caves, and subterranean streams entering the river, above Fort Snelling. Although the Trenton limestone exists in full force about St. Paul, in the bluffs east and north of the city, yet it had been cut through by some means prior to the drift so as to allow the entrance and exit of streams of water at levels below its horizon through the sandstone. None such are found above Fort Snelling. The surface drainage is shed by the limestone, and is precipitated over the brink of the gorge, forming several beautiful cascades. When such streams enter the river below Fort Snelling, they either enter some subterranean passage and appear at the mouths of caverns in the sandstone, or as springs in the drift along the talus, or they find an ancient ravine down which they plunge, by a series of rapids over bowlders, to the river-level, rarely striking either the lime-rock or the underlying sand-rock. Again, the rock-bluffs at St. Paul, and everywhere below Fort Snelling, are buried under the drift-sheet. Their angles are sometimes seen jutting out from some wind-beaten corner, but nearly everywhere they are smoothed over by a mantle of drift and

loam. Even the immediate river-bank, where the lime-rock should be intact, shows that it has been extensively disrupted and its *débris*, often coarse and water-worn, in pieces from four to ten feet long, is mixed with the coarse bowlders, gravel and the drift, at the height of fifty to seventy-five feet above the water-level, the heterogeneous mass lying on the worn upper surface of the St. Peter sandstone. But above Fort Snelling the upper edge of the lime-rock is intact all the way to the falls, and shows a fresh-cut section. It is surmounted by a continuous sheet of drift, which rises from the water-level in one bluff coincident with the rock-cut. Its individual strata show that they were cut by the recession of the falls in the same manner as the strata of the rock. They do not conform in their undulations to the outline of the rock, as if the gorge were present when they were formed, as at St. Paul. There is no spreading of loam over these cut edges, except such as has fallen down from above at the time of their removal or subsequent to it. At Fort Snelling, the direction of the Mississippi changes abruptly at a right angle. The change is caused by entering the wide gorge which runs in that direction. This gorge is that in which the Minnesota runs, and is out of proportion with the amount of water which it carries. This valley continues in the same direction, and with the same width, beyond the confluence of the Mississippi, but takes the name of the latter stream. At one mile below the mouth of the Minnesota it is a mile and a half wide.

These features of greater age, pertaining to the bluffs of the Mississippi below Fort Snelling, are seen in the old rock-bluffs of the river above the mouth of Bassett's Creek as far as to Shingle Creek. The rock there is deeply changed in color, and is hid by the drift, and the bluffs, as left by the more ancient river, are far apart, the old gorge being three or four times as wide as that between the falls and Fort Snelling. These rock-bluffs, consisting of the same limestone as that which at the falls is below the water, here rise from thirty to forty feet above the river, and are buried under loam, or under drift and loam. This part of the old valley continues southwardly, by way of Bassett's Creek (below its last turn), across the western suburbs of Minneapolis, through the valleys occu-

pied by Lakes Calhoun and Harriet, and joins the Minnesota at some point above Fort Snelling, the precise locality being

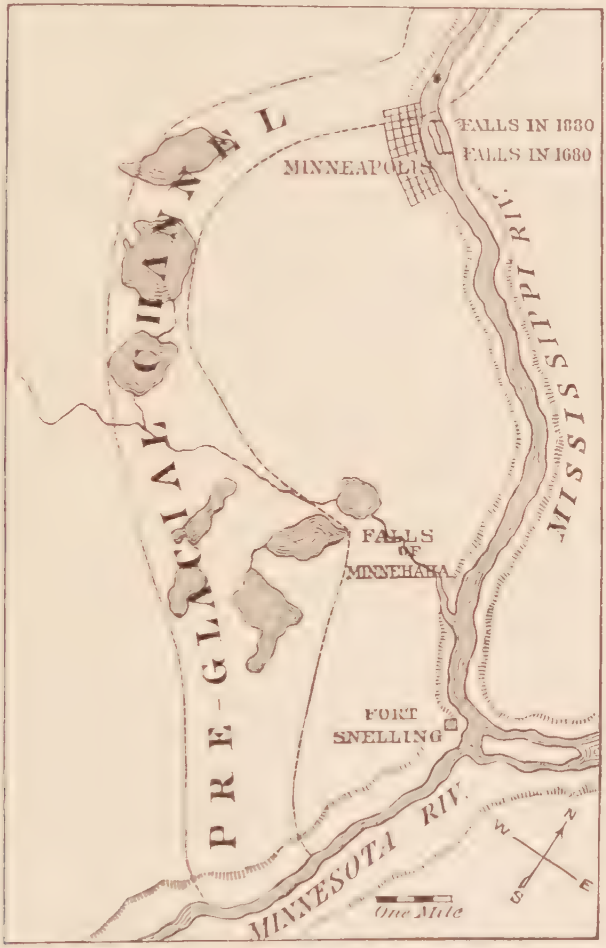

FIG. 142.—Map of Mississippi River from Fort Snelling to Minneapolis and the vicinity, showing the extent of the recession of the Falls of St. Anthony since the great Ice age. Notice the greater breadth of the valley of the Minnesota River as described in the text.

hid by a subsequent deposit of drift. It was cut down into the St. Peter sandstone over one hundred feet at least, as shown by the well at the Sumner school-house, and about two

hundred and seventy-five feet, as shown by the deep well at the Lakewood Cemetery. This would show that probably the ancient valley of the Minnesota where it passes Fort Snelling, and all the way through Ramsey county and below, has been filled more than two hundred feet by drift that originated since the excavation of the gorge. This supposition is borne out by all borings that have been made between the rock-bluffs at lower points, as at West St. Paul and at Lake City. Such excavation is not found in the river-gorge between Fort Snelling and the Falls of St. Anthony; but, below the water, are found, first, some large fragments of limestone, and some bowlders of foreign origin, the whole being generally less than twenty-five feet in thickness, and below that the undisturbed St. Peter sand-rock is found, suitable for the foundation of piers for bridges.

These facts warrant the conclusion that that part of the Mississippi gorge above Fort Snelling has been excavated by the recession of the falls since the last general drift movement, and that prior to that event there was a gorge which passed from the present channel of the Mississippi at the mouth of Bassett's Creek southward to the great gorge of the Minnesota at some place above Fort Snelling. It is probable that this gorge was then occupied by waters that drained from the northern part of the State, and had existed through many ages, dating back to pre-Cretaceous times. It seems to have been filled first by a blue till, or partly filled, and to have remained free for the passage of the Mississippi during the on-coming of the Glacial epoch, till the advent of the ice of the last Glacial epoch, when morainic accumulations so choked it that the water of the river was driven out and compelled to seek another passage to the Minnesota. When this last event took place, the Falls of St. Anthony probably began at Fort Snelling, the water being precipitated over the rock-bluff of the pre-existing old gorge, unless the whole valley was too deeply buried under water. Whether this was at the beginning or at the acme of cold, or at the recession of the ice, is a question which may well be considered, but at this time the only point that is claimed is that it was not earlier than the beginning of the last Glacial epoch, and was probably near the acme of cold.

Having thus established the post-glacial origin of the gorge below the Falls of St. Anthony, the next point was to determine the rate at which the recession has been proceeding. Fortunately, upon this point an abundance of evidence is available. The falls were first visited and described as early as 1680 by the Jesuit missionary Hennepin. His description is found in the Amsterdam edition of his works, printed in 1704. The falls were again visited in 1766, eighty-six years later, by Carver, another Jesuit missionary. In addition to his description this traveler made a sketch of the falls, which was engraved to accompany his travels, published in London in 1778. Subsequent travelers who describe it are Major Z. M. Pike, in 1805; Major Stephen S. Long, in 1817; Schoolcraft, in 1820; Professor William Keating and Mr. Beltrami, Rev. W. T. Boutwell and Schoolcraft, in 1832; and Mr. G. W. Featherstonhaugh, in 1835. In addition various artists have gathered descriptions of the falls as they appeared in 1842, 1848, 1853, and in 1857, and daguerreotypes were taken in 1851; while in 1853, before the erection of sawmills, Mr. J. W. Bond gave a careful description of the falls as they then existed, and numerous living witnesses fix their position in 1856, when artificial changes were introduced, which so modified the rate of recession as to disturb further calculation. The period, then, during which evidence is available for calculation is that between Hennepin's visit in 1680 and the year 1856—one hundred and seventy-six years. The descriptions are so minute that Professor Winchell is able to fix beyond doubt the various stages of recession between these dates.

In 1680 the falls were near the south end of Hennepin and Spirit Islands, not far above the present Tenth Avenue Bridge. In 1766, at the time of Carver's visit, the falls had receded about four hundred and twelve feet, and were at Carver's Island. In 1856 the west falls were about five hundred feet below their present position, which is now made stationary by artificial means. According to Professor Winchell, the recession from 1680 to 1766, between Hennepin and

Carver, was four hundred and twelve feet; and between 1766 and 1856, six hundred feet, making a total between 1680 and 1856, of one thousand and eighteen feet. "These give respectively the rates 4·79, 6·73, and 5·08 feet per year, and for the corresponding periods necessary for the recession of the falls from Fort Snelling (a distance of a trifle over eight miles) 8,819 years, 6,276 years, and 8,315 years. The average of these three results is 7,803 years."

Professor Winchell then proceeds to discuss the possible elements of error in this calculation:

1. That arising from difference in the volume of the river. The terraces already described in the chapter on "Preglacial Drainage," as characterizing both the Minnesota River and the upper Mississippi, reveal the existence of enormous floods during the closing stages of the Glacial period. Indeed, these floods in the Minnesota River were so high as to fill it up to the level of the lime-rock at Fort Snelling, about one hundred feet. During the existence of this high water, therefore, there could have been no cataract at Fort Snelling or farther up the Mississippi. The Falls of St. Anthony could have begun only after the floods of the Minnesota began to shrink so as to uncover the lime-rock at Fort Snelling.

2. Difference in the height of the falls at various points from Fort Snelling up to its present position. This is shown to be comparatively insignificant, so that it can be left out of the account.

3. The stage of the Glacial period when the recession began. Upon this we quote again at length:

This point has already been considered in the possible variations in the volume of the river. It is probable that the Mississippi, in diminutive form, began to flow in its new channel at the acme of the cold,* since the moraine of the second Glacial epoch runs across the country, approximately through this region, and since it would have remained in its

* See map of Minnesota in next chapter (Fig 181).

preglacial channel till it was driven out by the encroaching moraine. It was the easier removed from its old channel by reason of its reduction in volume. When it began its course in its new channel, it flowed over a broad plain of gravel and sand, the then latest accumulations of glacial torrents. This plain of gravel and sand extended throughout the adjoining space now occupied by such drift deposits. The same kind of deposits filled the whole Minnesota Valley, from side to side, and rose as high as the plains back of Fort Snelling. The river, being comparatively small, had but little effect on these deposits. If it excavated any channel, the torrents from the ever-present glacier-ice filled them at once—indeed, *it* excavated, *it* refilled, as *it* was glacier-born. It was on the retirement of ice, bringing a greater drainage area into contribution to swell the main streams at this latitude, that these rivers began to deposit the fine loam-sand which covers the coarse gravel and sand of these terraces. It was still later, when the rivers were shrunk, by the partial or complete withdrawal of the glaciers from their remote sources, that they began to excavate through the loam and the gravel and sand and finally entered on the slow erosion of rock-gorges. Thus it appears that the date from which the recession of the falls must be reckoned was after the outlet of Lake Agassiz had been opened toward the north, one of the last acts of the Ice age. . . .

Finally, if all the supposed irregularities be allowed their full force, and all the elements of doubt be admitted, their combined effect would not, at the most, more than slightly modify the result. And even if it should double the first result, or should reduce it to one half, the chief value of the calculation is not impaired. That consists in showing the lateness of the last Glacial epoch compared with the enormous time that has sometimes been supposed to have elapsed since its departure.

If the occurrence of our winter in aphelion, caused by the precession of the equinoxes and the revolution of the line of the apsides, about eleven thousand three hundred years ago was the cause of our last Glacial period, it follows that it required about thirty-five hundred years for the withdrawal

of the ice-margin from the vicinity of Fort Snelling to that place where the discharge of Lake Agassiz was opened toward the north, reducing the Minnesota to nearly its present size. This change must have given prominence and erosive effect to the waterfall at Fort Snelling, if it did not give it birth.

These calculations concerning the age of Niagara and the Falls of St. Anthony are amply sustained by the study of various minor waterfalls and gorges in Ohio to which I have myself given special attention. For example, at Elyria, twenty-five miles west of Cleveland, Black River plunges over the outcropping Waverly sandstone, and flows onward to the lake through a wide valley in the Erie shale, which was doubtless preglacial, though no buried channel above has yet been discovered. The gorge below the falls, which has been eroded since glacial times, and which approximately represents the work done by Black River during that time, is only a trifle over two thousand feet long. The water flowing over the falls represents the drainage of about four hundred square miles, and the sandstone which forms the precipice over which the water plunges is underlaid by soft shale very favorable to rapid erosion. In March, 1871, a mass of rock fell which was so large that the concussion shook the whole town and produced the semblance of an earthquake. With the present forces in operation at this point, it would seem incredible that the average rate of recession should not be considerably more than one foot in fifty years. Yet thus infinitesimal would be the rate if one hundred thousand years must be allowed for the time separating us from the birth of the present waterfall at Elyria. The shortness of this and other similar gorges in that region points to a great reduction of the prevalent estimates of glacial chronology.

Another interesting confirmation of this moderate estimate is to be found in Paint Creek Valley, in the southern part of Ohio, to which attention was directed in a previous chapter. As was discovered by Professor Orton several years

ago, this stream, a few miles above its junction with the Scioto, at Chillicothe, abandoned its preglacial valley in a most singular manner.* The preglacial valley of Paint Creek for about twenty miles above its junction with the Scioto runs in a northeast direction from the town of Bainbridge. The valley is nearly a mile wide at the bottom, and about five hundred feet below the general level. But the present stream, after it has abandoned this old valley, occupies for two or three miles a narrow gorge not over five hundred feet wide, cutting directly through the table-land, and reentering the old valley considerably lower down in its course. The only satisfactory explanation of this is found in a study of the local glacial phenomena. The lower or northeastern part of this preglacial valley is exactly on the line of the glacial boundary, and was for a certain period obstructed by the most advanced portions of the glacier, which dammed up the water and raised it to a level at which it would be forced in front of the ice across a tongue of the table-land, thus eroding the present channel.†

This portion of the channel, as already indicated, is about three miles long, from three hundred to five hundred feet deep, five hundred feet wide at the top, and two hundred at the bottom. The walls near the top consist of fifty or sixty feet of Waverly sandstone, while all below is a soft shale crumbling very readily. The question in glacial chronology is to find the age of this gorge, which is clearly post-glacial. The true solution of the problem comes from a study of one of the lateral gorges formed by a small tributary entering the main gorge midway from the south. This tributary, though dry a portion of the year, is at other times a raging torrent, and drains an area of two or three square miles. Yet in the soft shale, so favorable for rapid erosion, it has worn a gorge less than six hundred feet long, but having a mouth of nearly the same width where it joins the

* "Geological Survey of Ohio," vol. ii, p. 653.

† See map, p. 373.

main channel. It can scarcely be possible that these forces have been in operation in their present position for many thousand years; for, according to the testimony of Mr. Long, who has been a resident upon the ground for fifty years, and has definite data for calculation, this tributary creek has worn back several feet since his remembrance. If the rate of recession for this tributary gorge were as little as one foot in twenty years, only twelve thousand years would be required for the accomplishment of the work done. If we should go back to the period assigned by Mr. Croll's theory to find the Glacial period, the rate of recession would be incredibly slow, and far below what is pretty certainly the rate at the present time.

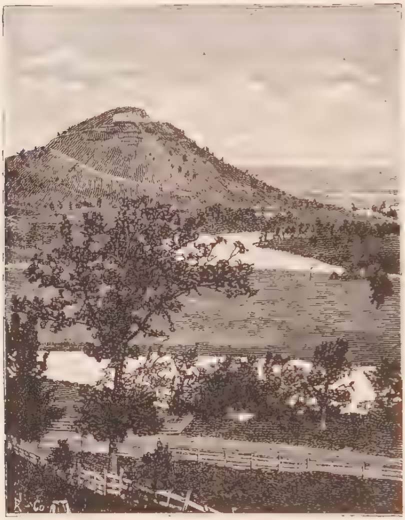

FIG. 143.—Ideal view of an old unglaciated country, showing the form assumed by the eminences when erosion has proceeded to a great extent. (United States Geological Survey.) (Chamberlin.)

An extreme length was at one time given to the interglacial episodes by attributing to interglacial time much erosion that was preglacial. For example Professor Chamberlin in his early publications regarded the gorge of the Ohio and the Allegheny as well as those of the Delaware and the Lehigh as the work of interglacial erosion. If this were the case, the interglacial episodes must have been of enormous extent, for these are rock gorges of great length and 200 or 300 feet in depth.

Subsequent investigations, however, showed that the most of this erosion was preglacial rather than interglacial. At Warren, Pennsylvania, on the Allegheny River, as already

detailed, the upper gravel terraces which Professor Chamberlin had separated from the lower ones by this enormous interval, were found to be continuous, showing that they belonged to the same period, while deeply buried gorges filled with glacial *débris* of Kansan age opened into the main channel from the south. As already remarked, also, the high-level terraces of the Monongahela were not, as Professor Chamberlin maintained, ordinary river flood-plains, but shore lines of a glacial lake produced by damming up of the outlet into Lake Erie, by way of the Mahoning and Grand River valleys.

FIG. 144—A country, in contrast with that on the opposite page, in which the drainage has been disturbed by glacial deposits and the streams are beginning to wear new channels. (Chamberlin.)

The most, therefore, that can be made of the interglacial time from the erosion of the Ohio River gorge is that needed for the wearing down of the cols between the branches of the various streams that were flowing north and were dammed up by the advancing ice-sheet. As already shown it was the junction of these upper branches which formed the present tortuous channel of the Ohio River. The gorge of the Delaware was proven to be preglacial by the investigations of Professor E. H. Williams, which brought to light the fact that at Bethlehem, Pa., the present Lehigh River flows over a bed of glacial *débris* filling an old channel which is 120 feet deep, and this in a region reached only by the very earliest ice invasion. The rock gorge of the Delaware into which the Lehigh empties must, therefore, be wholly preglacial.

Another most instructive illustration of the extent of preglacial erosion is found west of Keokuk, Iowa,* where there is a buried channel of great width now filled with glacial *débris* while the river at Keokuk flows over a rock bottom and through a comparatively narrow channel.

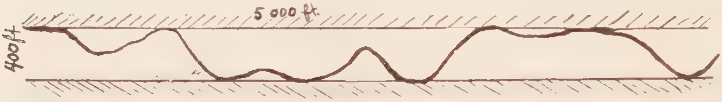

FIG. 145—Meanderings of Plum Creek through 5000 feet of its trough.

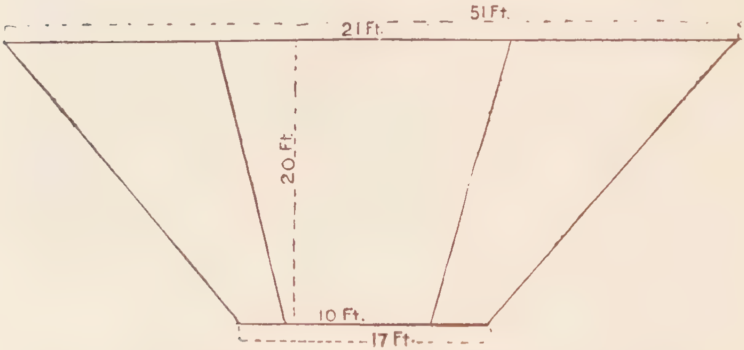

FIG. 146—Cross section of the new course of Plum Creek, showing its original width and its enlargement in twelve years.

Another means of measuring thhe amount of erosion since the Glacial period is found in post-glacial river-valleys by estimating the amount of material which has been carried out by the present streams from the glacial deposit itself.

Professor Hicks, of Granville, Ohio, reported in 1884,† some important results of such an investigation in the valley of Raccoon Creek, Licking county, near the glacial border. Thi present flood plain of this creek is now bordered on either side by gravel terraces about fifty feet high, which are

* See cut on page 310.

† "Baptist Quarterly" for July, 1884. See also Fig. 99, p. 324.

evidently the remains of a modified glacial deposit formerly filling the whole valley to that height. Since the Glacial period the present stream has been occupied with the task of slowly removing this material. The number of cubic yards which it has already carried away can be approximately estimated. The rate of removal is more difficult to determine. Assuming the rate to be the same per cubic foot of water as that which is transported by the Mississippi River past New Orleans, which doubtless is far too small, the time required would be, according to the calculation of Professor Hicks, less than fifteen thousand years.

I have been able to make a more definite calculation in connection with Plum Creek, in Oberlin, Ohio. The situation is peculiarly favorable both on account of its relation to the glacial shore lines around Lake Erie, and of its freedom from disturbing obstacles. The section of the Creek Valley from which the facts are gathered lies ten miles south of the present shore of Lake Erie, and 250 feet above the lake level. It is about five miles south of the highest of the lake ridges, and fifty feet higher than the upper ridge. Its course is wholly in glacial till with no rock bottom anywhere in its course. The average gradient of the stream is twelve feet to the mile, falling 100 feet in eight miles. It is evident that the stream did not begin the erosion of its present trough until the ice-sheet had retreated from the water-shed on the south and had uncovered the outlet of the glacial lake at Fort Wayne, which determined the level of water on whose shores the upper ridge was thrown up by the waves. The Plum Creek trough is therefore older than the Niagara gorge by the length of time that was required for the retreat of the ice-sheet from the south shore of Lake Erie to the Adirondack Mountains, a distance of 200 or 300 miles; for, as already said, Niagara did not begin its work until the Mohawk Valley, south of the Adirondack Mountains was free from ice.

Now, in 1895, a reservoir was constructed in the village occupying the whole width of the trough of the creek, and

compelling the engineers to open a new channel across an undisturbed neck of the original glacial till. The section of this chosen for observation was 500 feet long, and at first consisted of a ditch twenty-one feet wide at the top, and ten at the bottom, with an average depth of eleven feet, though on the south side it rose to a height of twenty feet above the bottom. But, after a lapse of twelve years (in 1907), the stream had enlarged the ditch to a width of fifty-one feet at the top, and of seventeen feet at the bottom, giving an average width of thirty-four feet compared with the original of fifteen and one-half feet. A simple mathematical calculation shows, therefore, that in twelve years this stream had removed from a 500-foot section whose banks were exposed to the direct action of the current on both sides, 101,750 cubic feet of solid matter, or, 8,450 cubic feet per annum.

To get a more perfect basis of comparison, measurements were taken of a section 5,000 feet long below the village, where the original conditions had been undisturbed. In this section the eroded trough averaged 400 feet in width and seventeen feet in depth, and this entirely in glacial till such as characterizes the whole valley. The total amount, therefore, of work accomplished, by the stream in this section since the present line of drainage was opened was the removal of 34,000,000 cubic feet of till.

To obtain a still more approximate basis for calculation it was necessary to measure the length of the sections of the edge of the trough where the stream impinges directly against the bluff and so is eroding under conditions similar to those in the cut-off at the reservoir. Upon doing this it was found that these exposed sections amounted to 1,600 feet in length, which is 600 feet more than that of both sides of the cut-off. The annual erosion, therefore, in the 5,000-foot section is now one and six-tenths greater than in the cut-off, making 13,568 cubic feet of material per year. At this rate the 34,000,000 feet of material from the 5,000-foot section

would be removed in 2,505 years; a result so incredible that we are called to examine more closely into the various conditions affecting the problem, some of which would tend to retard the eroding action of the stream, and some to accelerate it.

Of the retarding influences the most conspicuous is the former existence of a dense forest of large trees covering the whole basin. It is scarcely possible, however, that the rate would be reduced from this cause lower than to one-tenth of that of the present time, which, if there were no counteracting causes, would extend the time to 25,000 years.

But, on the other hand, it is evident that the rate of erosion in the main trough is, at its present width, at a minimum. For, as the width of the trough has enlarged, it has taken the stream a longer and longer time to swing from side to side in its meanderings. At the outset the stream acted through the entire length on both sides as it now does in the cut-off, and when the width of the trough was half what it is now, the erosion was twice as fast.

It is safe to say, therefore, that the average rate during the forested condition would be twice what we have allowed. This would reduce the time to 12,500 years, which cannot be far from a correct estimate. For, in addition to the early constriction of the channel in increasing the rate, it should be kept in mind that on the first withdrawal of the ice there was no forest to retard the action of the stream. Furthermore, it is altogether probable that there was a much greater precipitation over the basin of the creek while the ice lingered over the area immediately to the northward, and this would increase the rate of erosion.

It has been necessary to enter thus fully into details concerning one instance in order to get the force of the cumulative argument from the innumerable similar instances which present themselves all over the area in which the natural drainage is towards the front of the ice-sheet. Present

eroding forces cannot have been at work over this region for much more than 10,000 years, and this is some time previous to the beginning of the work of the present Niagara River.

Another class of facts which seems to set moderate limits to glacial chronology relates to the amount of superficial erosion of glacial deposits of various sorts, and the extent to which the rocks have been disintegrated since that period.

President T. C. Chamberlin, when State geologist of Wisconsin, remarked that no sensible denudation had taken place there since glacial times.* Even Mr. Croll expresses surprise at the small amount of erosion which has taken place since the kames of Scotland were deposited. Both in Europe and in America these peculiar relics of the Glacial period retain a sharpness of outline which it is difficult to believe could have survived the protracted period of one hundred thousand or even of forty thousand years, according to Hitchcock's reckoning. When, also, one considers the chemical agencies at work to decompose the rocks wherever unprotected by a covering of till, the freshness of the glaciated surfaces never ceases to be a cause of astonishment.

Dr. Geo. F. Becker, of the United States Geological Survey, bears striking testimony to the freshness of the glaciated surfaces of the rocks in the mountains of California on the Pacific Coast. He writes:

"No one, who has examined the glaciated regions of the Sierra can doubt that the great mass of the ice disappeared at a very recent period. The immense areas of polished surfaces fully exposed to the severe climate of say from 7,000 to 12,000 feet altitude, the insensible erosion of streams running over glaciated rocks, and the freshness of erratic bowlders are sufficient evidence of this. There is also evidence that the glaciation began at no very distant geologic date. As Professor Whitney pointed out, glaciation is the last important geological phenomenon and succeeded the great lava flows.

* "Geology of Wisconsin," vol. ii, p. 632.

"There is also much evidence that erosion has been trifling since the commencement of glaciation, excepting under peculiar circumstances, east of the range, for example, at Virginia City; and sites which there is every reason to suppose preglacial have scarcely suffered at all from erosion, so that depressions down which water runs at every shower are not yet marked with water-courses, while older rocks, even of tertiary age and close by, are deeply carved. The rainfall at Virginia City is, to be sure, only about ten inches, so that rock would erode only say one-third as fast as on the California coast; but even when full allowance is made for this difference, it is clear that these andesites must be much younger than the commencement of glaciation in the north-eastern portion of the continent as usually estimated. So, too, the andesites near Clear Lake, in California, though beyond a doubt preglacial, have suffered little erosion, and one of the masses, Mount Konocti (or Uncle Sam), has nearly as characteristic a volcanic form as Mount Vesuvius."*

Dr. Bell† also writes as follows: "On Portland promontory, on the east coast of Hudson's Bay, in latitude 58°, and southward, the high, rocky hills are completely glaciated and bare. The striæ are as fresh looking as if the ice had left them only yesterday. When the sun bursts upon these hills after they have been wet by the rain, they glitter and shine like the tinned roofs of the city of Montreal." Again, Professor Macoun‡ writes of the red Laurentian gneiss in the vicinity of Fort Chippewayan, at the west end of Lake Athabasca: "The rocks around the fort are all smoothed and polished by ice action. When the sun shines they glisten like so much glass, and a person walking upon them is in constant danger of falling."

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* "Bulletin of the Geological Society of America," vol. ii, pp. 196, 197. To the same effect see the testimony of Prof. I. C. Russell and Prof. Gilbert, below p. 609.

† "Bulletin of the Geological Society of America," vol. i, p. 308.

‡ "Geological Survey of Canada, Report of Progress," 1875-1876, p. 90.

"Likewise, concerning the glaciation of Europe, we find that in Wales and in Yorkshire, England, the amount of denudation of limestone rocks on which bowlders lie has been regarded by Mr. Mackintosh* as a proof that a period of not more than six thousand years has elapsed since the bowlders were left in their positions. The vertical extent of this denudation, averaging about six inches, is nearly the same with that observed in the southwest part of the Province of Quebec by Sir William Logan and Dr. Robert Bell, where veins of quartz marked with glacial striæ stand out at various heights not exceeding one foot above the weathered surface of the enclosing limestone.

As illustrating how little we know about the causes which produce the variations in snow fall, even from year to year, and render it impossible to form trustworthy a priori opinions concerning the proximity of the causes which are capable of producing glacial conditions, Mr. Becker writes that in 1890 the "snowfall in the Sierra was exceptionally large, about two and one-fourth times the average precipitation having fallen. Much of this snow remained unmelted through the season, and when I left the mountains, on October 1, there were still thousands of snowbanks where in ordinary seasons none remains even far earlier in the season. Many of these banks were also of great depths, say 100 feet, more or less. It is clear, therefore, that were this and succeeding winters to be as wet as the last, the range would show glaciers in great numbers, much as the Alps now do; in short, the glacial period of the Sierra would recur in a moderate way. Now, no one doubts that there was some cause for the unusual snowfall of 1889–90 but no one has any suspicion what it was. No sensible change in cosmical or terrestrial conditions has occurred, the weather of the world at large was not remarkable, and, excepting as to precipitation, the year was not extraordinary even in California."

* "Quarterly Journal of the Geological Society," vol. xxxix, pp. 67-69; vol. xlii, pp. 527-539.

Again evidence comes from the extent to which lakes, dating from the Glacial period, have been filled with sediment. Little reflection is required to make it evident that our present lake-basins could not always have existed; for, except where counteracting agencies are at work, the "wash" of the hills will, in due time, fill to the brim all inclosed areas of depression. Mr. Upham, of the Minnesota Geological Survey, expresses surprise at the small extent to which the numerous lakes of that State have been filled with the sediment continually washing into them. "The lapse of time since the Ice age has been insufficient for rains and streams to fill these basins with sediment, or to cut outlets low enough to drain them, though in many instances we can see such changes slowly going forward." *

Dr. E. Andrews, of Chicago, has made calculations, deserving of more attention than they have had, concerning the rate at which the waters of Lake Michigan are eating into the shores, and washing the sediment into deeper water or toward the southern end of the lake.† The United States Coast Survey have carefully sounded the lake in all its parts, and have ascertained the width of the area of shallow water extending inward from the shores. It is well known that waves are limited in their downward action, so that there will be a surrounding shelf, or shoulder of shallow water, in cases where the waves of a deep lake are eroding its banks. This fringe of shallow water encircling Lake Michigan is only a few miles wide; and from such data as have been gathered, the average rate of erosion is found to be as much as five or six feet per annum; which would indicate that the lake-basins had not been in existence more than seventy-five hundred years.

Leaving these more indefinite and in many respects unsatisfactory efforts to estimate the age of lake-basins, we may get some assistance in approximating to a correct chro-

* "Minnesota Geological Report" for 1879, p. 73.

† "American Journal of Science," vol. xcviii, 1869, pp. 172 *et seq.*

nology of the Glacial age by studying the smaller kettle-holes which constitute so marked a feature in the kames and moraines of the glaciated region. As already shown, the most satisfactory explanation of these curious depressions is, that they mark places where masses of ice were buried in the *débris* of sand and gravel brought down by the streams of the decaying glacier ; and where, upon the melting of the buried ice, a cone-shaped depression was left with sides as steeply inclined as the nature of the soil would permit. At any rate, there can be no question that the kettle-holes were formed during the closing stages of the Glacial period.

As typical of numberless others we present the facts concerning a kettle-hole near Pomp's Pond in Andover, Mass.*

Pomp's Pond is itself a moraine basin about a quarter of a mile in diameter, and but slightly above the level of the Shawshin River, into which it empties. Upon its north side is an accumulation of gravel and sand, with pebbles intermingled, in which there are several of the smaller characteristic bowl-shaped depressions of which we have spoken. Their appearance is much like that of volcanic craters. You ascend a sharp acclivity from every side to a rim of gravel, and then descend as rapidly into the bowl-shaped or crater-like depression. A section carried across will present the idea.

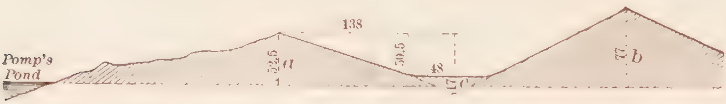

FIG. 147.– Section of kettle-hole near Pomp's Pond, Andover, Massachusetts. (See text.) (For general view of the situation, see Fig. 101, p. 338).

From the level of the pond, and two or three rods from the edge, you begin to ascend at an average rate of about one foot in three, till the south side of the rim is reached, at a height of fifty-two and five tenths feet above the pond. (*a*) (This rim is not, however, of a uniform height. On the east side it rises

* I here transfer a few paragraphs from my "Studies in Science and Religion."

into a pyramid seventy-seven feet high.) (*b*) Then, descending fifty and five tenths feet vertically, you are carried one hundred and thirty-eight feet horizontally, reaching at that point the edge of a circular mass of peat which is ninety-six feet in diameter. (*c*) From the opposite side the ascent of the northern rim begins, and you descend from its top to the valley, repeating almost exactly the first descent from the pond. The distance from rim to rim, or the diameter is three hundred and eighty feet.

It is evident that since the first formation of this crater-shaped depression no material can have reached the bottom, except from three sources: 1. The wash from the side; 2. The decay of vegetation which grew within the circumference of the rim; 3. The material brought by the winds. It is equally evident that what is once in can not get out.

Dust, leaves, and twigs carried by the winds inevitably lodge in such depressions more thickly than in other places, since the atmosphere in such hollows is comparatively quiet. For the same reason the surrounding trees as they are blown down are more likely to fall toward the center of the kettle-hole; and the ashy material which their roots abstract from the sides of the depression is no insignificant factor in the problem.

Now, from the angle of the declivity, the original depth of the depression can be approximately estimated. If the angle be still the same as at first, the first three terms of the proportion would be 138 : 50·5 : : 48 : $17\frac{1}{2}\frac{3}{3}$, making the original depth below the present surface of the peat a trifle over 17·5 feet. If, however, we suppose the original slant to have been steeper and the rim higher, we can still see that there must have been a limit to the depth. Suppose the rim to have been one third higher and the slant one third steeper, we then should have in round numbers the proportion 138 : 68 : : 48 : $23\frac{1}{2}\frac{5}{3}$, making the original depth of the depression nearly twenty-four feet below the present surface of the peat. From the nature of the material it is impossible that the depth could originally have much exceeded that amount.

Accepting this conclusion, the problem is, to determine the time it would require the agencies mentioned above to fill the

bottom of this bowl to a depth of twenty-four feet—a cone ninety-six feet in diameter at the base and twenty-four feet to the apex—which would be equal to a deposit of only *eight* feet over the present surface of the bottom. The question is, Could this have stood with so little change for eighty thousand years; or even for forty thousand years, if we were to accept Professor Charles H. Hitchcock's estimate of the prolongation of the effects of Croll's period?* Is not the supposition of ten thousand years sufficiently extravagant? If the close of the great Glacial period be so far back as Mr. Croll estimates, we must believe that sediment would accumulate, in the situation above described, over the surface of the present peat-bog, at the rate of only one inch in a thousand years; while, if we put the close of this period back ten thousand years, the rate of accumulation would seem to be as slow as our imagination can well comprehend. One hundred inches, which is little more than eight feet, divided into one hundred thousand parts, would be only ·001 of an inch; that is, if this depression has been in existence one hundred thousand years, we must believe that with all the dust there is in the air, and all the soil that would wash down the steep incline of all the sides, and all the vegetable matter growing in and falling into the depression, one thousand years would be required for one inch of sediment to accumulate! If we reduce this supposed period to 50,000, 25,000, and 12,500 years successively, the time required for the accumulation of an inch of sediment would be proportionally 500, 250, and 125 years. If any one will be at the trouble of dividing an inch into 125 equal parts, he will probably be surprised at the insignificance of the quantity. The slowest rate at which Boucher de Perthes calculates for the accumulation of peat over Roman pottery in the valley of the Somme is three centimetres, or a little over an inch, in a century.

We do not bring railing accusation against those who, from astronomical considerations, confidently speak of the close of the Glacial period as an event which occurred scores of thousands of years ago; but it is important to know what other

* "Geology of New Hampshire," vol. iii, p. 327.

beliefs that long chronology carries with it. If any one chooses to believe that kettle-holes can stand one hundred thousand years, and fill up only twenty-four feet from the apex of the inverted cone, he must run the risk of being considered credulous.

In rejecting the theory of Mr. Croll concerning an indefinite succession of glacial periods, we did not mean to foreclose the discussion connecting the question whether there have not been several Pleistocene glacial epochs. This question must, therefore, now be considered with more particular reference to its bearing upon matters of chronology. As the reader doubtless observed in the remarks upon Croll's theory, quoted from Mr. Gilbert and President Chamberlin, in the preceding chapter, each of them spoke of an "Interglacial Period" as clearly indicated in North American geology. The calculations just made relate to the chronology of what President Chamberlin called the "second glacial epoch." Niagara Falls, the Falls of St. Anthony, the kettle-holes of Massachusetts, and the valley of Plum Creek, are none of them upon the extreme border of the glaciated region. Raccoon Creek is nearer the margin. Calculations respecting those interior points, therefore, do not give the date of the extreme marginal deposits. Hence it becomes a matter of prime importance to consider to what extent the ice retreated during the various climatic episodes which characterized the epoch. Many, perhaps most, of the authorities on glacial subjects at the present time hold that during two or three of these episodes the ice retreated as far as the Laurentian Highlands and then re-advanced to the limits of what are called respectively, the Iowan, the Illinoisan and the Wisconsin boundaries of glacial drift. It is necessary, therefore, to discuss these questions in considerable detail.

The most obvious evidence adduced in favor of interglacial epochs in America consists of the so-called "inter-

glacial" forest-beds.* These forest-beds and vegetal deposits occur over a wide area, and in places have glacial deposits both under them and over them. The first supposition with regard to them was that these various forest-beds were contemporaneous, and indicated a general retreat of the ice after its first invasion of North America until it had entirely disappeared or lingered only in the Canadian highlands; whereupon there was a readvance of the ice, overwhelming the forests and other vegetal deposits which had collected in kettle-holes and other depressions, and burying them beneath a second sheet of ground-moraine, where they are opened to present inspection whenever wells penetrate them or eroding streams expose them on their banks. But it is not clear that these interglacial forest-beds might not originate in front of the margin of the slowly retreating ice if only there were comparatively brief periods of readvance along successive lines of latitude. Thus they may belong to various times of oscillation, both during the general advance and during the general retreat of the glacier. If, for example, at any time during the period of advance there had been a retrocession of the ice-front for a short distance, forests and vegetable growth would soon have spread over the marginal belt from which the ice had retreated, and, upon a readvance, these would be overwhelmed and covered with a new stratum of glacial deposition. In case of some of the peat beds, it is probably necessary to suppose that they were formed where they are, and are really interglacial; but, in case of many of the fragments and logs of wood found in the glacial deposit, we are not compelled to suppose an interglacial origin. Wood will stand transportation in the ground-moraine almost as well as bowlders, and it is by no means certain that much of the timber found in the till may

* See Chamberlin, "Geology of Wisconsin," vol. i, chap. xv, especially pp. 271–291; "Driftless Area," pp. 211–216; N. H. Winchell in "Proceedings of the American Association for the Advancement of Science," vol. xxiv, 1875, pp. B, 43–56; "Geology of Minnesota," vol. i of the "Final Report," pp. 363 *et seq.*; J. S. Newberry, "Geological Survey of Ohio," vol. ii, pp. 30–33.

FIG. 148. Perpendicular section of till at Oxford, Ohio, showing a piece of wood three inches in diameter projecting from the face. This has evidently been transported in the till like a bowlder. The section is about fifty feet; portion shown, about fifteen feet, near the middle. (United States Geological Survey.) (Wright.)

not have belonged to the original forests which covered the country in front of the first sheet of advancing ice. These logs may have been picked up like the bowlders, and transferred to the south a long time after their original deposition. Thus, it may be that the "forest-beds" near the margin of the glaciated area are of more recent origin than those some distance back, since the ice in its final retreat may have proceeded with few and slight oscillations. As President Chamberlin suggests, also, "certain subaqueous deposits so closely resembled true till that they have been mistaken for it, and there is perhaps no case of superposition of beds supposed to represent two glacial periods that is not still open to these doubts."*

President Chamberlin, whose knowledge of the facts bearing on this subject is wider than that of any one else, therefore does not rely so much upon the existence of inclosed forest-beds and a supposed superposition of distinct beds of glacial *débris*, in proof of distinct glacial epochs, as upon certain other considerations of a more general nature, such as the following:

The earlier drift is characterized, in the interior basin, by a wide but relatively uniform distribution, manifesting only occasional and feeble tendencies to aggregation in morainic ridges. It is not bordered, except in rare instances, by a definite terminal moraine, but ends in an attenuated border. It is not characterized by the prevalence of prominent drumlins or other similarly ridged aggregations. The phenomena of glacial erosion connected with it are generally feeble. Glacial striæ are indeed present, even in the peripheral portions, but the surface of the rock is not usually extensively planed. The whole aspect of the deposit indicates an agency which spread the drift over the surface smoothly, and relatively gently, with little forceful action. The drainage phenomena are also of the gentle order. We have yet failed to find evidence of very vigorous drainage connected with the older drift of the in-

* See "Geology of Wisconsin," vol. i, p. 272.

terior basin except in osars and kames, whose conditions of formation were exceptional, but, on the contrary, abundant proof of slow-moving waters and imperfect drainage, indicating low slope of the surface.

The later Glacial epoch, on the contrary, was characterized by strong glacial action, planing the rock-surface vigorously, even up to the very limit of its advance. The glaciers plowed up immense moraines about their edges, except on smooth plains whose slope was away from the ice-movement. The drainage was usually vigorous, and immense trains of glacial gravel stretch away from the margin of the ice-sheet, reaching great distances down the valleys and frequently filling them to great depths with well-assorted material. The vigorous action of the glaciers of the second epoch and the rapid drainage, in general, stand in marked contrast with the gentle action and imperfect drainage of the earlier epoch. One of the conditions that determined the distinction was probably the difference in elevation that characterized the two epochs.

The interval between these two leading epochs we regard as the chief interglacial epoch, representing a greater lapse of time and a greater change in the dynamic agencies of the age than the several other interglacial intervals, or episodes of deglaciation, which mark the complicated history of the Ice age.

As belonging to the earlier Glacial epoch, we recognize two drift-sheets that have been described by the geologists of the respective States as occurring in southwestern Ohio, southern Indiana, central and southern Illinois, eastern and southern Iowa, northern Missouri, eastern Nebraska, and southeastern Minnesota.

Between these occur, at numerous points, vegetal and ferruginous accumulations and other evidences of a non-glacial interval. To this horizon belong the larger number of deposits described under the term "old forest-bed," but very many vegetal deposits so referred do not, in our judgment, belong there, but are referable to several distinct horizons.*

Others adduce as evidence of the distinct Glacial epochs in North America the greater oxidization and general de-

* "Driftless Area," pp. 214, 215.

composition of the material upon the extreme border of the glaciated region as compared with that of the kettle-moraine in Wisconsin, and what is considered to be a moraine of corresponding age in the regions both east and west.

A striking evidence of the reality of this difference in oxidization is related by Professor Penck. When Mr. Frank Leverett was visiting him in Germany the two went out together into the Alpine fields where Professor Penck had distinguished three well marked stages of glaciation of increasing amounts of oxidization and erosion. These successive periods of glacial and interglacial episodes he had named after three streams in the foothills of the Alps in southern Germany, where the deposits are typically present; viz., Mindel, Riss and Würm.* In every instance Mr. Leverett was able to correlate these with the three divisions which he had made in America; viz., the Kansan, corresponding to the Mindel period; the Illinoisan to the Riss; and the Wisconsin to the Würm. But he did not recognize the Iowan. All these identifications were made in the field without previous knowledge of Professor Penck's determinations. But with reference to this evidence it is to be noted:

1. That the more complete oxidization of the glacial *débris* along the southern border and the greater decomposition of the granitic bowlders and pebbles distributed over this border, are naturally accounted for by the obvious fact that for the most part the material along the southern border, and for some distance back from it, was that which was first picked up by the advancing ice, and was probably already oxidized and partially decomposed by the long-continued action of preglacial agencies when the ice began its removal. Its oxidization, therefore, may not be any true indication of the remoteness of its transportation and deposition. It is evident that every successive period of movement from the north would operate upon lower strata of rock and upon the masses which had been less affected by secular agencies of

* See above page 459.

decomposition. Thus it is natural that the more northern moraines and glacial deposits, of various kinds, should appear fresher than the southern.

The peculiar facts brought to light concerning the oxidization of the belt of oldest till, bordering the Wisconsin moraine, in Pennsylvania, are worthy of close attention in this connection. As already noted, Professor Williams found by extensive field work that the moraine as marked by Lewis and Wright across Pennsylvania was not the extreme boundary of glacial action, but lay on an average twenty or twenty-five miles back from that boundary. This attenuated border was referred to by Lewis and Wright as "the fringe," but they did not endeavor to ascertain its limit in that state. The deposits over that area would, however, now be correlated without doubt with those of Kansan age in the Mississippi Valley.

It is noteworthy, therefore, that the surface outcrops over this attenuated belt (examined in thousands of places and at all elevations in eastern Pennsylvania up to 650 feet above tide, and under caps of glacial deposits only a few feet thick, that vary from loose gravels to compact clays) are universally fresh and undecomposed, showing that the already oxidized deposit was laid upon a freshly glaciated surface, and that time enough has not since elapsed to decompose or oxidize the gneiss, limestone, and slate rocks to any appreciable extent. A striking illustration of this has already been given in connection with the mammoth coal-beds at Morea, Pa., within one mile of the extreme limit of glaciation, and twenty-five miles south of the moraine of Lewis and Wright (p. 154). Here the surface of the rock is distinctly glaciated, and covered with from six to ten feet of sandy till through which water easily percolates. But the coal is rotted only to the depth of three-fifths of one inch, while immediately south of it, in the unglaciated region, it is rotted to the depth of many feet.

2. The till over this attenuated border is a mixture of fresh and oxidized material at all levels, showing that most of the oxidization preceded the glaciation, and that not sufficient time has elapsed since for the oxidization of the fresh material picked up by the glacier. This statement is based upon the examination of sections miles in length; when it everywhere appears that there is such a mixture of fresh material with oxidized material that the conclusion is irresistible that it was one movement which brought both.

For example, in the vicinity of Warren and south of Oil City at an elevation of 380 feet above the Allegheny River numerous pebbles were found, both of sedimentary and of granitic rocks, which had evidently been oxidized nearly to their center before starting on their journey from Canada, but had been planed down on one side so as almost to expose the core on that side, while leaving the oxidized layers undisturbed on the other. Some of these described were five inches or more in diameter and had been rotted so that only an inch or more of fresh nucleus remained; while in some cases the unoxidized core was exposed through the glacial erosion of one side. These instances were numerous. Mr. Williams informs me that "one striking peculiarity in those with joint planes through which the water could readily reach the center, was that the relative permeability of the mass from its different sides did not have the slightest influence on the position of the fresh nucleus. It was as often nearer the side whence water could most easily enter than to any other side. This impressed me greatly," he says, "as an indication of the extreme recency of the final shaping as with time the relative porosity of the various sides would tend to bring the remaining nucleus under the usual law as to position."

I am permitted, also, to use the following extract from Professor William's unpublished notes, in which he sums up some most significant facts concerning the Kansan advance:

"The glaciated outcrops in the east [in Pennsylvania] are

solid: those in the west more oxidized and rotten, but the critical condition in the west as in eastern Pennsylvania is the constant presence and mixture of fresh rolled material. As the age of the mixture is the age of the freshest part, there is finally no difference between the ages of the eastern and western Kansan drift.

"The rustiness of the western gravels shows that they were the rolled and weathered surface fragments picked up by the ice, and modified by its action. With the crystallines which are thoroughly oxidized to their center, we find a few specimens which look on one side like a piece of rusty gravel. The black bisilicates have entirely disappeared, and have left pits and a rusty staining. The feldspar also has kaolinized. In these very old ones, the glaciated sides were never scraped down to the fresh interior, but uniformly show a rusty though solid exterior, quite smooth and firm to the hammer.

"By breaking these, we would find that the solid nucleus might be one-eighth of an inch from one side which had been glaciated, and three inches or more from the other side which had remained unglaciated."

I am not aware that adequate attention has been paid to this class of facts over the Illinoisan and Kansan areas in the Mississippi Valley, but I was much impressed with the freshness of the Canadian bowlders which were found at Tuscumbia, on the Osage River, in central Missouri, and by the freshness of many of the pebbles in a great gravel-pit at Holliday on the Kansas River a few miles above Kansas City to which the railroads have resorted for a long time for ballast and which contains much material from the far north.

In this connection it is proper to call special attention to the accumulating evidence going to show that the glacial movement from the Keewatin center was not strictly contemporaneous with that from the Labradorian center but preceded it by a longer or shorter interval.

In the first edition it was suggested that the remarkable re-entrant angle in the glacial border at Salamanca, N. Y., indicated the junction of two ice-movements from widely

separated centers of accumulation to the northeast and northwest. Positive evidence in support of this was found, as already stated, by Prof. Williams in 1897 in the discovery of a rolled piece of native copper from Lake Superior firmly imbedded in till at East Warren, Pa., forty feet below the surface, showing that the older ice-movement from the northwest invaded the region now coverd with the later deposits from the northeast to the extent of several hundred miles; for, as already shown, northeastern drift extended some distance across the Mississippi at Burlington, Iowa.

The most important evidence supposed to indicate the complete retirement of the continental ice-sheet between successive deposits is found near Toronto, Canada. This was first investigated by Dr. G. J. Hinde in 1878, but has since been more thoroughly studied by Professor A. P. Coleman, of Toronto University. Briefly stated the facts are that in the valley of the Don River and at Scarboro Heights near Toronto there is at the base a deposit of till which after having been extensively eroded was covered by sedimentary deposits 150 feet in thickness which had been brought into standing water by the stream to form a delta whose base extended twenty-five or thirty miles along the shore. The lower strata of this delta deposit are thirty-five feet below the present level of the lake, and probably at about the same relative level as when laid down. But the water from some unknown cause rose as the accumulation progressed until it was 150 feet higher than now, when the upper sediments of coarser gravel were deposited the water began to fall, and a period of erosion succeeded.

This proceeded until at Scarboro a V-shaped channel, one mile wide at the top and 150 feet deep, was worn in the sedimentary deposits, whereupon the ice advanced again and covered the whole with sheets of bowlder clay and assorted drift to a total depth of 200 feet. Here certainly seems to be an interglacial deposit of unusual extent.

Nor is the character of the fossil plants and animals included in the interglacial deposits any less noteworthy.

Both the fauna and the flora of the lower, or Don, beds indicate a much warmer climate than those of the upper, or Scarboro beds. In the Don beds there are found leaves and wood of maple, elm, ash, hickory, basswood, and even of pawpaw and osage orange which new flourish only in latitudes several degrees south of Toronto. Also, of the mollusks found in the Don beds, four of the species are not now found in the St. Lawrence basin, but only after passing the watershed which separates it from that of the Mississippi.

On the other hand, the upper, or Scarboro sands and clays are wanting in the species indicating a warmer climate but abound in both a flora and a fauna suggestive of Labrador and of the region north of Lake Superior.

In the opinion of Professor Coleman these facts cannot be accounted for except on the supposition that the earlier ice-sheet retired from practically the whole region to the northward before the latter one began its advance; which certainly looks very reasonable at first sight. But there are a number of considerations, too much overlooked, which perhaps permit a contrary conclusion.

1. We are not warranted in assuming that the advance of the ice was simultaneous from the Keewatin and the Labradorian centres. On the contrary it seems certain, as has been shown above, that the advance from the Keewatin center was much earlier than from the other. The so-called Kansan till underlies the Illinoisan for several hundred miles east of the Illinoisan border. For example the Illinoisan ice crossed the Mississippi at Burlington, Iowa, and advanced many miles westward. But Kansan ice had at an earlier time spread eastward so as to carry Lake Superior copper as far as Warren in Western Pennsylvania. In a previous chapter (p. 527) attention is called to the fact that the boundary of the glaciated areas in the central and eastern parts of the United States consists of the arcs of two circles with their centers respectively in Labrador and the Lake Superior region. This will appear at a glance by consulting the map. Now,

the junction of these arcs is at Salamanca, New York, almost exactly on the meridian of Toronto. It is therefore a plausible hypothesis that the lower till at Toronto was deposited by the Keewatin ice-sheet near its eastern margin and that it withdrew some time before the Labradorian sheet reached that point.

This opens up a wide field of speculation connected with our theories of the cause of the spread of the various ice-sheets. On the theory that elevation of land is the prime cause it would appear that the rise of land proceeded in a wave from west to east. The Keewatin center therefore rose first and sent out its ice-sheets far south to Kansas, and east to Pennsylvania. Then as it began to sink under its accumulating load of ice, the eastern or Labradorian center began to rise and in due time started its glaciers to meet the vanishing ones from the Keewatin center. But, possibly long before Toronto was reached by the Labradorian ice-sheet, the Keewatin glacier had retired from its eastern limit amid conditions of climate that were essentially preglacial. For it must be borne in mind that the retreat of the ice can only take place when the climate is abnormally warm. Indeed such warmth would seem to be essential for the melting of the ice.

An interesting direct proof of this was found by Dr. Holst in southern Sweden, where he excavated gravel beds in front of the principal moraine which contained remains of plants and animals characteristic both of warm and cold climates in close connection, and which must have been contemporaneous. Similar facts were reported to me by Professor Tschernaschev from Finland. It is also well known that large species of oysters lived long after the glacial epoch in Maine, especially at Damariscotta, which do not survive except on our southern coasts. It is in point also to instance the spread of the mastodon, the mammoth, the rhinoceros and even the hippopotamus under the conditions which prevailed in northern Europe and Asia during the glacial period.

A further line of inferences follows from studying the probable cause of the rise of the water in Lake Ontario during the accumulation of the interglacial delta at Scarboro. This, as we have stated, was 150 feet, and the deposits at the bottom indicate a warm climate, and those at the top a cold climate. Now if we study the conditions involved it will appear that there is strong confirmation of the theory just advanced. Evidently, as Professor Coleman points out, the deposition of the Don beds began when the level of Lake Ontario was just about what it is at the present time. That would imply that its outlet was still through the St. Lawrence, which must then have been unobstructed by ice. But as the Labradorian ice advanced and closed up this outlet the water level would eventually rise to the height of the col at Rome, N. Y., leading through the Mohawk into the Hudson River. This is 200 feet above Lake Ontario. But as it is shown that now the axis of post-glacial elevation is the Mohawk Valley, the north shore of Lake Ontario may well have been relatively fifty feet higher during glacial times than it is now, which would bring the elevation of the col at Rome into exact harmony with that of the upper Scarboro beds. Under this theory we have that gradual passage from warm to colder conditions which we need to account for the change in species in passing from the lower to the upper beds. And this is just what Dr. Lamplugh has shown to be the case in the glacial deposits of England.*

2. The uniformity in the distribution of the till over the southern portion of the glaciated area in the Mississippi Valley is partly an illusion, due to the fact that the great amount of loess covering the region, especially in southern Indiana and Illinois and in eastern Nebraska, prevents, to a considerable extent, observations upon the original surface, and this loess, as has already been shown, is doubtless the

* "Presidential Address to the Geological Section of the British Association for the Advancement of Science," at York, 1906.

finer part of the glacial *débris* carried southward by the glacial streams—so that, upon any theory, we should expect a much larger accumulation of loess over the southern portion of the area.

Mr. Leverett relies largely on the great erosion of the Kansas sheet till as an indication of its age. He estimates, for example, that in northern Missouri not over thirty per cent of the original plain is left upon the retreat of the ice, in the narrow tabular remnant remaining upon the divides. "The streams are flowing in valleys that have broad slopes and bottoms, the slopes being so toned down as to fall generally below 5° and not uncommonly to 3° or even less. The slopes of the valley, twenty-five meters in depth, often have a breadth of about a kilometer, and the bottoms of small drainage lines often exceed a kilometer in width. Topographic sheets of the United States Survey, which well illustrate the post-Kansan erosion, are the Atlanta, Edina, and Kahoka quadrangles of northern Missouri." (See comparison of North American Glacial Deposits, from "Zeitschrift für Gletscherkunde," vol. iv, p. 258).

With this he compares a part of the Belleville, Ill., topographic sheet which shows 60 per cent or more of the original glacial plain untouched by erosion; but again in the Iowan drift (which Mr. Leverett would now identify with the Illinoisan epoch), the portion of the glacial plain which is undissected is not greatly in excess of the Kansan plain from Missouri.

It should be noted furthermore that the blanket of Kansan till is comparatively uniform over its whole area. There are no moraines in it, and there never were any. Moreover, the deposit was rarely thick enough to disguise the preglacial topography. Much of the supposed evidence of post-glacial erosion is probably the result of this failure of the glacial deposits to fill the valleys and channels of the original topography.

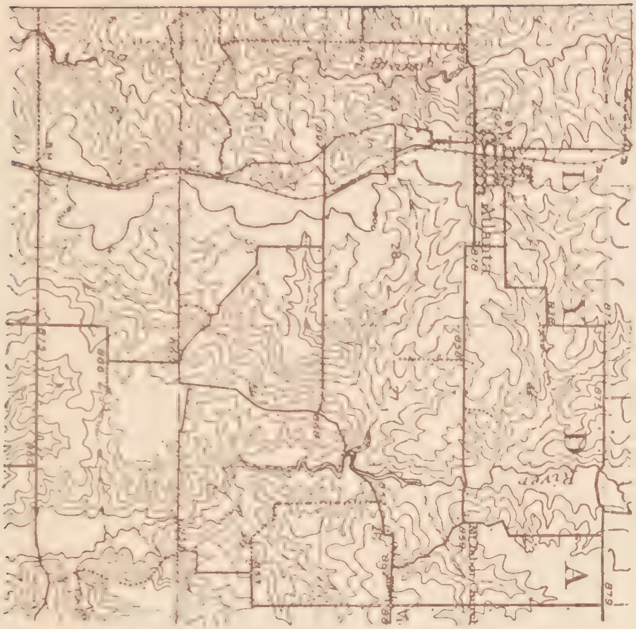

FIG. 149.—Part of Atlanta, Missouri topographic sheet. Scale $\frac{1}{12}$ Million or 1:83333. Contour interval 20 feet. Illustrates post-Kansan erosion.

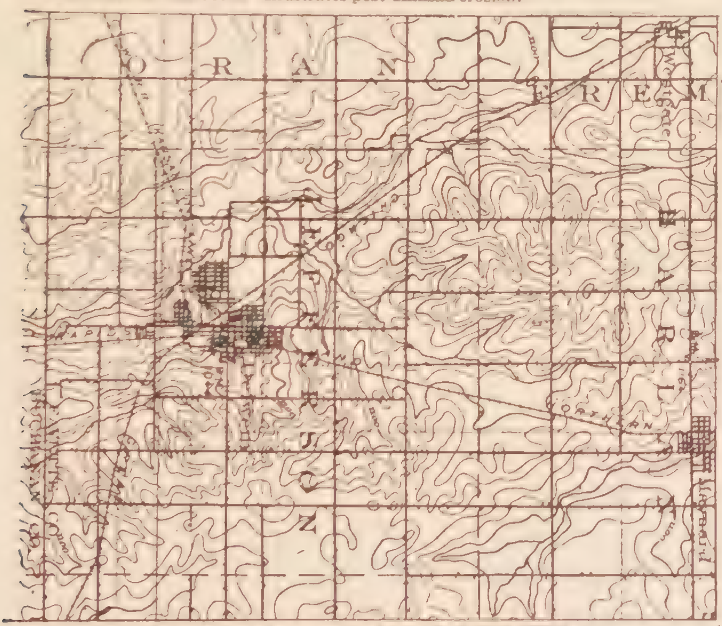

FIG. 150.—Part of Oelwein, Iowa, topographic sheet. Scale $\frac{1}{4}$ or 1:62500. Contour interval 20 feet. Illustrates erosion in the so-called Iowan drift.

The controlling influence of the preglacial topography may be observed in the neighborhood of Galesburg, Illinois, where all along the divide between the Illinois and Mississippi rivers the surface presents an extensive general level, covered with glacial drift of Illinoisan age to a considerable depth. But as one proceeds on either side towards the rivers mentioned the size of the preglacial valleys increases so rapidly that the glacial blanket is not sufficient to disguise them, while near the water-shed on both sides appear the original extensive amphitheaters characteristic of valleys of extreme age.

Evidently the post-glacial erosion is not by any means so great as would at first appear to be the case. But what seem to be valleys of post-glacial erosion are simply adjustments of the glacial blanket to the precedent valleys of erosion.

Again, the broad valleys bordering the south-flowing streams of gentle gradient in the Illinoisan and Kansan regions differ only in moderate degree from similar valleys in the Wisconsin area. As instances I would note the valleys of the Nishnabotna, the Tarkio, the Nodaway, and the Platte rivers of northwestern Missouri, all of which rise in southwestern Iowa, and, after flowing long distances, enter Missouri. One can but be impressed in crossing these valleys with their great width, and with the signs that they were occupied by immensely larger streams of water than it is possible to provide under present conditions. On comparing these valleys with that of the river Styx, a small stream in Wisconsin drift just south of the water-shed in Medina County, Ohio, we find a very small stream occupying a level flat-bottomed valley, a third of a mile wide, which is evidently the product of the lingering ice and the floods pouring through the valley during the melting of the late Wisconsin period. The contrast between this valley and the valleys in northwestern Missouri is by no means great, certainly not so great as to imply an enormous lapse of time between their formation.

In both cases, doubtless, the wide troughs were preserved by the presence of lingering masses of the melting ice sheet.

3. The theory of a general depression of the glaciated area with reference to the sea-level may apply to a certain portion of a single period as well as to one of two distinct periods. We may suppose a low slope of a surface and the consequent imperfect drainage and slow-moving waters during the maximum extent of a single glacial epoch as well as during the first of two epochs. The theory that the weight and attraction of the ice were tangible factors in producing the relative depression of land which characterized a portion of the Ice age would lead us to expect the greatest depression during the period of maximum extension. When the ice-front had retreated from Carbondale, Ill., to Madison, Wis., the intervening area had been relieved from an enormous amount of pressure.

4. With reference to the comparative absence of glacial striæ and of planing and grooving over the southern area, it should be noted, first, that fresh exposures of rock in that region are very infrequent, owing to the great depth of till and loess; and, secondly, that upon any theory the glacial grooving and striation would necessarily grow fainter as the boundary was approached, because the movement of ice over that portion was so much less than over the central and northern portions; and, thirdly, the absence of planation is not relatively so great as is sometimes represented. The grooves and striæ in Highland and Butler counties, Ohio, very near the margin, and in southwestern Indiana and southern Illinois, still nearer the margin, are as clear and distinct as can anywhere be found. Also, upon the surface of the limestone rocks, within the limits of the city of St. Louis, where the glacial covering was thin, and disintegrating agencies had had special opportunities to work, I found very clear evidences of a powerful ice movement; and at Du Quoin, Ill., only forty or fifty miles back from the extreme limit of glaciation, I was greatly impressed with the extent to which the surface rock had been planed, by ex-

amining the fragments brought up from a shaft which had recently been sunk first through fifty or sixty feet of surface soil, and then for some distance into the rock. The small fragments from the surface of the rock thrown up were most beautifully planed and striated.

A thorough study of the condition and distribution of the buried forest-beds bears strongly, as I can not but think, against the complete separation of glacial epochs in North America. In addition to the facts about to be enumerated, it is a significant circumstance that the buried vegetable deposits under consideration do not mark a warm climate, but a climate much colder than the present—such a vegetation, in fact, as would naturally flourish near the ice-margin. The buried forests of southern Ohio have a striking resemblance to those we described in Glacier Bay, Alaska. Peat and hardy coniferous trees are predominant.

One of the most instructive localities in which to study organic remains embodied in glacial deposits is in the region included in the southern part of Montgomery and the northern part of Butler county, Ohio. The glacial deposits containing organic remains in that vicinity were first described by Professor Orton, of the Ohio Survey, in 1870.* Near Germantown, on Twin Creek, in Montgomery county, about thirty miles north of Cincinnati, there is exposed, at a sharp angle of the stream, a perpendicular bank of drift ninety-five feet in height. Underneath this is a deposit of peat as much as fourteen feet thick. The upper portion of the peat "contains much undecomposed sphagnous mosses, grasses, and sedges." Both the stratum of peat and the clayey till above "contain many fragments of coniferous wood, some of which can be identified as red cedar (*Juniperus Virginianus*)." Immediately above the peat-bed there is from fifteen to twenty-five feet of what seems to be true till. This shows no sign of stratification, and abounds in striated stones. Next above occurs a band about ten feet thick of stratified

* "American Journal of Science," vol. c, 1870.

material containing coarse gravel and a good deal of fine sand. Above this to the top seems again to be true till,

FIG. 151.—Section of till near Germantown, Ohio, overlying thick bed of peat. The man in the picture stands upon a shelf of peat from which the till has been eroded by the stream. The dark spot at the right hand of the picture, just above the water, is an exposure of the peat. The thickness of the till is ninety-five feet. The partial stratification spoken of in the text can be seen about the middle of the picture. The furrows up and down had been made by recent rains. (United States Geological Survey.) (Wright.)

with, however, an occasional pocket of sand or thin stratum of stratified material. But, both up and down the stream from this point the till merges into gravel-beds partially ce-

mented together by infiltrations of lime and iron. Down the stream the stratum of peat rises to a higher level, so as eventually to come in contact with the first band of stratified material just mentioned, the intervening till gradually thinning out between them. The appearance is that of a saucer-shaped deposit of peat such as would have formed in a kettle-hole, and which was subsequently filled and covered with the advance of the glacier.

That the facts indicate a somewhat prolonged interval between the first advance of the ice over the immediate region and the second, can not, therefore, well be denied, for the peat is clearly enough between two glacial deposits. But it may well be questioned whether an interval of two or three centuries would not suffice for the accumulation of the peat described; for it will be observed that it seems to have occurred in a large kettle-hole in which the vegetable matter naturally gravitated toward the center and is much deeper there than near the edges. It is not therefore allowable to take the extreme thickness of peat as the measure of the amount of accumulation during the interglacial period.

As to the rapidity with which peat may accumulate in favorable circumstances, we can do no better than transfer a recent discussion of the subject from the pen of the veteran botanist, Leo Lesquereux, contributed to the "Annual Report of the Pennsylvania Geological Survey for 1885": *

Two conditions are necessary for the origin and growth of peat—water either stagnant in basins, lakes, pools, etc., or water abundantly supplied by a boggy atmosphere, increased by dense forest-growth.

Pools of stagnant water, when not exposed to periodical drying up, are invaded by a peculiar vegetation: first, mostly composed of *confervæ*, simple, thread-like plants, of various color and of prodigious activity of growth, mixed with a mass of infusoria, animalcules, and microscopic plants, which, partly decomposed, partly continuing the floating vegetation, soon

* Pages 106, 107, 113, 114.

fill the basins, and cover the bottom with a floating of clay-like mold. So rapid is the work of these minute beings, that in some cases from six to ten inches of this mud is deposited in one year. Some artificial basins in the large ornamental parks of Europe have to be cleaned of such muddy deposits of floating plants, mixed with small shells, every three or four years.

When left undisturbed this mud becomes gradually thick and solid—in some cases of great thickness, affording a kind of soil for the growth of marsh-plants, which root at the bottom of the basins or swamps and send up their stems and leaves to the surface of the water or above it, where their substance becomes in the sunshine hard and woody.

As these plants periodically decay, their remains, of course, drop to the bottom of the water; and each year the process is repeated, with a more or less marked variation in the species of the plants. After a time the basins become filled by these successive accumulations of years or even centuries, and then the top surface of the decayed matter, being exposed to atmospheric action, is transformed into humus and is gradually covered by other kinds of plants, making meadows and forests.

In this way many deposits of peat are buried underground and remain unknown until discovered by diggings or borings. Such are the immense peat deposits in the great swamps of Virginia, the Dismal Swamps, and all along the shores of the Atlantic from Norfolk to New Orleans.

In other cases when basins of stagnant water are too deep for the vegetation of aquatic plants, Nature attains the same result by a different special process, namely, by the prolonged vegetation of certain kinds of floating mosses, especially the species known as sphagna. These floating masses grow with prodigious speed, and, expanding their branches in every direction over the surface of ponds or small lakes, soon cover it entirely. They thus form a thin floating carpet, which, as it gradually increases in thickness, serves as a solid soil for another kind of vegetation that of the rushes, the sedges, and some kinds of grasses, which grow abundantly mixed with the mosses, which by their water-absorbing structure furnish a persistent humidity sufficient for the preservation of their re-

mains against aërial decay. The floating carpet of moss becomes still more solid, and is then overspread by many species of larger swamp-plants and small arborescent shrubs, especially those of the heath family; and so, in the lapse of years by the continual vegetation of the mosses, which is never interrupted, and by the yearly deposits of plant remains, the carpet at last becomes strong enough to support trees, and is changed into a *floating forest*, until, becoming too heavy, it either breaks and sinks suddenly to the bottom of the basin, or is slowly and gradually lowered into it and covered with water. . . .

The absorbing power of the peat-mosses enables them to grow higher and higher above their original water-level, from which they thus gradually emerge. The name *emerged bogs* has been therefore given them.

The peat of emerged bogs is less compact; the annual layers are more distinct, generally well defined in their succession. At the top of the bog the layers measure about one inch in thickness, at the bottom less than one eighth inch, and in old bogs still less. The growth, therefore, though not very rapid, is easily observed and registered in several ways.

It may be measured by compass and level from the border of the swamp, the central portion of which becomes gradually higher and higher, screening from the view of a spectator on one side of it objects which had been before observable on the other side of it.

It may be estimated also by a time-scale, in cases where ancient bridges, pavements, etc., whose epoch of construction is certified by documents, are discovered buried under beds of peat of known thickness.

Again, in places where peat-bogs have been worked for a number of years, old pits are encountered, now entirely refilled; and when this happens with peat, during the life of the proprietor, who has himself dug the old pits and can recall the exact date, very precise data are thus furnished for learning the amount of time necessary for the reproduction of a given thickness of peat.

The rate of growth depends, of course, on atmospheric or other local circumstances, but, putting together many such pieces of documentary testimony obtained in different coun-

tries, the average production of compact matter may in a general way be estimated at one foot in a century.

In *immerged bogs*, formed of vegetable *débris* falling into water, the peat grows more slowly and less regularly. The actual rate of its growth has not yet been positively recorded. In very extensive bogs, stretching between Swiss lakes, timber posts have been discovered on the line of an old road, and parts of a bridge buried beneath five or six feet of compact, black peat. Although the exact date of these constructions has not been fixed, the discovery of Roman medals in the vicinity suggests the beginning of the Christian era. This shows that the kind of peat which results from the maceration of plants under water is of much slower growth than the peat layers of the *emerged bogs*. It is also more compact, and is quite black, the vegetable matter being more completely decomposed, and its internal structure generally so destroyed as to be unrecognizable. The peat of *emerged bogs*, on the contrary, is yellowish-brown, fibrous, its annual layers distinct, and the woody fragments more generally recognizable.

Since the above was written a well sunk at Germantown through the till 100 feet deep, nearly a mile northeast of the exposure shown on p. 593, penetrated a peat layer several feet in thickness, showing that the deposit is extensive and perhaps older than we had estimated. It should also be said that Mr. Leverett is not fully convinced that the gravel underneath the peat is glacial, but thinks that it probably is.

But we are not compelled to assume a slow growth, nor even the average growth as the rate. The cool, moist climate of a glacial age would seem to be peculiarly favorable to both the growth and the preservation of peat; so that two hundred or three hundred years is perhaps ample for the production of all the facts connected with the peat accumulations at this point. If it be asked how such a deposit of peat could be overwhelmed with ice without disturbance, the answer is that, as suggested by N. H. Winchell, before the reinvasion of ice the peat in the kettle-hole and probably the

rim of the whole had become frozen, and so capable of retaining its form.

Similar deposits of peat in superficial kettle-holes are very frequent in the glaciated region, and constitute an important portion of the reserved stores of fuel laid up for the future use of man. Professor Lewis and myself had an excellent opportunity to study such a modern deposit at Freehold, Warren county, Pa.* Here one half of such a hole had

FIG. 152.—Section of kettle-hole in Freehold, Pennsylvania. (See text.)

been removed in making a road, and exposed a complete and fresh section through the middle. The depth of the peat in the middle was six feet, growing gradually thinner in each direction toward the sides. Peat and soil were mingled in alternate layers near the edges. Numerous logs of prostrate trees were also imbedded in the peat. It is evident that had there been a readvance of the ice over this region after the above accumulation was complete, and had the soil become frozen, there would have been at Freehold an interglacial deposit of vegetable matter closely analogous to that described at Germantown.

A comparatively short interval between the periods of recession and advance of the ice-front in southern Ohio is also indicated in numerous places where fragments of wood are found imbedded in true glacial deposits near the glacial margin. For example, near Darrtown, on Four-Mile Creek, in Butler county, Ohio, is an exposure of till, sixty-five feet high, containing fresh red-cedar logs near the bottom, and fragments of wood in all conceivable positions throughout the lower half of the deposit. The deposit is true till, being unstratified and full of scratched stones, many of which are granitic. There is, however a line of stratified material

* See "Second Geological Survey of Pennsylvania, Z," p. 171.

about half-way up the bank, which is about two feet thick, and contains pebbles several inches in diameter. Not much

FIG. 153. – Section in till near Darrtown, Butler County, Ohio, sixty-five feet high. Coarse line of stratification near the middle. Fresh cedar logs at the bottom. (See text.) (United States Geological Survey.) (Wright.)

wood is found above this line, yet there is some, and the structure above seems identical with that below. All this would seem to indicate that there was a temporary retreat of

the ice, when for a short time water sorted and deposited material over the lower stratum of till; then there was a re-advance, pushing along a vast mass of unsorted material over the stratified stratum without disturbing it. In the deposit already described near Germantown, evidence of as many as four such marks of successive advances and retreats can be seen.

Again, near Oxford, in Butler county, a few miles up the same stream (Four-Mile Creek) from Darrtown is an exposure of till where the unstratified character is perfectly manifest in which I observed and photographed a piece of wood, well preserved, projecting from the perpendicular face of the bank about forty feet below the surface, and where no land-slide could have occurred.* Equally good sections were also seen on Aunt Ann's Run, near the city of Hamilton, in the same county, and only about twenty miles north of Cincinnati.

Usually, as has been remarked, these buried deposits of peat and wood have been assumed to imply the existence of two distinct glacial periods. But, from what has been said above, it would appear that the facts point rather to shorter periods of advance and recession of the ice-front, analogous to those which are now in progress in the Alpine glaciers, as heretofore noted. That the interval between the two movements noted at Darrtown was comparatively short is evident from the fact that the fragments of wood found mingled with the till, both above the stratum of stratified material and below it, are identical in kind, and are in a similar state of preservation. This locality is about twenty miles back from the glacial margin.

In the instances next mentioned of wood being found imbedded in glacial deposits the locality is still nearer the glacial margin, and, instead of being interglacial are preglacial—that is, the vegetable remains have glacial deposits over them but not under them.

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* See Fig. 148, p. 577.

A sycamore log was reported to me as found at Morgantown, Morgan county, Ind., thirty feet below the surface. This is, however, in a stratified deposit, but one which was evidently formed in connection with the last stages of the Glacial period at that point. It is one quarter of a mile back from the little creek running through the village, and the glacial limit is but a few miles south, on the higher lands of Brown county.

Again, near Seymour, Jackson county, Ind., logs of wood are reported as occasionally found in digging wells in the village at a depth of twenty feet below the surface. Seymour is on a glacial terrace, in the line of one of the largest glacial floods carrying off the melting torrents from the decaying ice over a good part of southeastern Indiana. The wide terrace on which Seymour stands, and in which the logs are found, is about sixty feet above the present bed of the East Fork of White River, running through the place. Black-walnut logs are also mined from the banks of the river in low water. This instance is not probably decisive of the age of the buried wood, as the terrace may be the product of the so-called second Glacial period. Still, there can be no doubt that the most recent glacial advance extended to the borders of Brown county, which lies a little west of the locality just spoken of, and which is nearly in the latitude of Butler county, Ohio, alluded to in a previous paragraph.

Another most decisive instance of vegetable remains in till near the margin occurs in Bigger township, in the southeastern corner of Jennings county, Ind. Here Mr. Burchill reported to me the finding of wood in a well, twelve feet deep, in a hard blue clay which, from neighboring exposures, is, without doubt, true till. On another farm, near by, wood was reported to me as found thirty feet below the surface in a well that failed to reach the rock at that depth. This is on as high land as there is in that region, and is about ten miles north of Madison, on the Ohio River, and about five hundred feet above it.

Professor Borden * reports a well at Paris Crossing, in Jefferson county, about twelve miles southwest of the foregoing place, in blue-drift clay forty feet below the surface. The same authority also reports a well at Milan, near the summit of Ripley county, Ind., which is as far south as Cincinnati, and about twelve miles northeast from the river, with muck and wood fifty-four feet down in what is evidently the true till of the region.

In Hamilton county, Ohio, the late Colonel Charles Whittlesey reported thirty-five wells containing muck-beds, leaves, or timber, from three hundred to five hundred feet above the Ohio River.† That at New Burlington is certainly in till.

In Highland county, Professor Orton reports many cases of the occurrence of such vegetable deposits. In the village of Marshall, "eleven wells out of twenty reached a stratum of vegetable matter with leaves, branches, roots, and trunks of trees." Marshall is on the very limit of the glaciated region. Similar instances were reported to me in the southern part of Highland county and in Clermont county.

In Ross county, near Lattas, Mr. J. M. Connell reported to me finding wood in a well, situated very near the extreme limit of glacial action, and where it could not possibly have been brought into position by means of water. The locality is four hundred and twenty-five feet (barometer) above the valley, just to the north, near Frankfort, and five hundred and twenty-five feet above the valley of the Scioto River at Chillicothe, ten miles to the east. The till is massed up against and upon the margin of a rocky plateau, here facing the north, in great quantities. The well described was in this marginal till upon the highest land, and passed through twelve feet of yellow clay, then through three or four feet of blue clay, then ten feet of yellow clay, then gravel for five feet. About thirteen feet below the surface there was

* "Geological Report of Indiana," 1875, p. 172.

† "Smithsonian Contributions to Knowledge," 1869, pp. 13, 14.

found a log of wood three or four feet long and about three inches in diameter. This was in the blue clay, and was accompanied with traces of muck.

There is not space to mention the many other places where wood is reported in the modified drift filling what are perhaps preglacial channels serving as outlets of the melting glacial torrents, and which may therefore have been transported a long distance from their native place. One such was reported to me in the valley of Raccoon Creek, in Granville, Licking county, Ohio, and but a few miles from the glaciated border. This was found ninety-four feet below the surface of the terrace, which would bring it about forty feet below the present bed of the stream. A few miles farther up in this same valley so many red-cedar logs were formerly found beneath the glacial terraces along the valley, and the wood was so fresh, that a flourishing business was for a while carried on in manufacturing household utensils from them. Red cedar is not found in that region now, and these logs are probably of the same period with those described as found in true glacial till in Butler county, and which are so fresh as to preserve still the peculiar odor of the wood.

Professor Collett reports that all through that portion of southwestern Indiana included within the glacial boundary there are found, from sixty to a hundred and twenty feet below the surface, peat, muck, rotted stumps, branches and leaves of trees, and that these accumulations sometimes occur through a thickness of from two to twenty feet.

We may mention, also, as probably connected with the period of the ice-dam at Cincinnati, the well-preserved organic remains found in the high-level terraces of various tributaries of the upper Ohio. In the vicinity of Morgantown, Professor I. C. White, as already noted, reports that, in the terraces which he connected with the period of the Cincinnati ice dam, the leaves of our common forest-trees are most beautifully preserved some distance below the surface, and that logs of wood in a semi-rotten condition were encountered seventy feet below the surface. At Carmichaels, in Wash-

ington county, Pa., a log of wood was also reported to me as found in a situation similar to that described by Professor White, buried thirty feet in the sand of a corresponding high-level terrace some miles back from the present bed of the Monongahela. Wood was also reported to me as found in a similar situation in terraces two hundred and fifty feet above the Alleghany River at Parker, Pa. The terraces there are many miles outside the glacial limit, but by their granite pebbles are unmistakably connected with the Glacial period. The wood was reported as dug from quicksand in a well two miles east of the river, and two hundred and fifty feet above it.

Another instance of wood which has been preserved in a deposit of the Glacial age is worthy of more minute description. In this case I have the advantage of having found it myself. The locality is that of Teazes valley, Putnam county, W. Va. This valley runs from the Kanawha River a little below Charleston to the Ohio at the mouth of the Guyandotte near Huntington. The valley, as already described,* is clearly enough a remnant of early erosion, when the water of the upper Kanawha took that course to join the Ohio. The valley is very clearly marked, being about a mile wide, and from two hundred to three hundred feet lower than the hills on either side, and having a remarkably level floor throughout the greater part of its course. The bottom of the valley is filled throughout with a deposit of river-pebbles covered many feet with a mixture of sand and clayey loam. In some places this loam is from thirty to forty feet deep, extending for several miles without interruption, as at Long Level, about the middle of the valley.† Here a section about half a mile long and twenty-five feet deep shows at the top a stiff stratum of clay containing wood at a depth of seven feet. Immediately below is sand containing much iron, and cemented together by the infiltrations of the ore. The stratum above, containing the wood, had never been disturbed,

* See p. 379.

† See Fig. 111, on p. 380.

and the wood (a small specimen of a knot of some coniferous tree) is remarkably fresh in its whole appearance. It is scarcely possible that it should have remained in such a position during the immense period supposed by Mr. Croll to have elapsed since the glacial age.

Many of these cases of subglacial vegetable accumulations are beneath or in deposits of the very earliest portion of the glacial period. Unquestionably of this age are those found in Jackson, Jennings and Jefferson counties, Indiana, and those found by Professor I. C. White in the terraces of the Monongahela River, which are now correlated with the earliest stages of the ice advance to the water-shed between the Great Lakes and the Ohio River.

Farther north, notably in Mower County, Minnesota, a stratum of peat from eighteen inches to six or eight feet in thickness, with much wood, is very uniformly encountered in digging wells, the depth varying from twenty to fifty feet. "From all accounts it (the peat stratum) appears to be embraced between glacial deposits of gravelly clay, and it seems to mark a period of interglacial conditions when coniferous trees and peat-mosses spread over the country . . There are extensive marshes now existing in northern Minnesota, mainly covered with ericaceous plants, with some cedar and tamaracks that are forming immense peat deposits. With an increase of the amount of moisture in the air such peaty accumulations would spread over much higher levels. A return of glacial conditions would bury such marshes below the deposits that are known as drift."*

The observations of Professor Tarr upon the burial of forests and peat bogs by the recent advance of glaciers in Alaska are deserving of the most careful consideration in our interpretation of the significance of the facts which are being here detailed.

* N. H. Winchell in "Geology of Minnesota," vol. i of "Final Report," p. 363.

"Along both the Atrevida and the Malaspina glacier margins, the glacier and glacial deposits are advancing in forested regions and overspreading old soils, peat beds, and forests. When the process of present change is at an end there will be in this region soil beds and plant beds interbedded with glacial deposits, and all as the result of a sudden change in glacier-margin conditions. It requires no elaboration of this subject to make it clear that here is a hint of great significance in the interpretation of pleistocene deposits. In view of such phenomena as those described above it is evident that the interpretation sometimes placed upon plant beds and soil beds intercalated in pleistocene deposits—namely, that they prove

FIG. 154—Forest lately disturbed and about to be overwhelmed by an advancing Alaskan glacier. (Photo by Gilbert.)

separate glacial epochs—can hardly stand without the support of other and convincing evidence that the plant or soil bed interval was of long duration."*

All this is in the region where the natural drainage is to the south; but, upon entering the northern water-shed, especially in the area now covered by the deposits of Lake Agassiz, interglacial deposits would seem necessarily to imply that the

* R. S. Tarr and B. S. Butler, "The Yakutat Bay Region, Alaska," "U. S. Geological Survey," "Professional Paper," 64, pp. 86, 87.

ice had melted back sufficiently to reopen the natural drainage lines of the Red River Valley into Hudson Bay. Mr. Upham confesses that beds of vegetal deposit which are both underlaid and overlaid by till are very rarely found in northern Minnesota. Still, he supposes some such are found, and gives an exhaustive list of instances.* The two which he mentions as being in the area of Lake Agassiz are encountered in digging wells, first, at Barnesville, Clay county, where twelve feet of till was penetrated, then one foot of quicksand "containing several sticks of tamarack up to eight inches in diameter; second, in Wilkin county, where the record is that till occupied the first eight feet, then a layer of gray sand one half an inch in thickness, then a much harder lower till for eighteen feet, which was underlaid by sandy black mud containing many snail-shells. But these two cases hardly seem sufficient to establish the theory, while the corresponding cases adduced by the Canadian geologists farther north are not described with sufficient minuteness to render their meaning unequivocal.†

Another class of phenomena bearing on the questions of the discontinuity and date of the great Ice age is to be found in the inclosed lake-basins lying between the Rocky Mountains and the Sierra Nevada, near the fortieth parallel. Numerous salt lakes now occupy this region. But it is evident, even upon hasty examination, that these are but insignificant remnants of those which formerly occupied it. Great Salt Lake is estimated to have contained at one period four hundred times its present volume of water. The terraces marking its former limits are very distinctly visible, and are nine hundred feet above its present level. Lake Mono has several distinct terraces, the highest of which is six or seven hundred feet above the present level. Pyramid and North Carson Lakes, in Nevada, are but the remnants of an immense salt lake extending from the Oregon boundary to latitude

* "Minnesota Geological Report for 1879," p. 48.

† "Report of Progress, Geological Survey of Canada, 1882–'84," p. 414, C.

38° 30′ south, a distance of two hundred and sixty miles. The Central Pacific Railroad is built through the bed of this lake for one hundred and sixty five miles, from the vicinity of Golconda to that of Wadsworth. This ancient lake has been carefully surveyed and described by Mr. I. C. Russell, of the United States Geological Survey,* and has been named

FIG. 155.—Sketch map of the Pacific coast, showing the outlines of the ancient lakes Bonneville and Lahontan. (Le Conte.)

* "Third Annual Report of the United States Geological Survey," pp. 195-235, and "Monograph XI," 1885.

Lake Lahontan, as that of which Great Salt Lake is the remnant was named Lake Bonneville, after the first explorers of the region. These basins have now no outlet to the sea. That of Lake Lahontan never had any; but, if the relative levels were the same at former times as now, Lake Bonneville at its greatest extent poured through Snake River into the Columbia.

During the year 1890 Mr. Gilbert published the first volume of his monograph upon Lake Bonneville—the ancient enlargement of Great Salt Lake, Utah—to which reference has just been made above. Mr. Gilbert estimates that at its maximum stage the area of this lake was 19,750 square miles—that is, about ten times the present size of Great Salt Lake—and that its maximum depth was one thousand and fifty feet, as compared with about forty feet at present. The climatic changes indicated by the studies of this ancient lake correspond closely with those indicated by Mr. Russell's study of Lake Lahontan as detailed on page 607. Early in post-tertiary times there was a great rise in these lakes, though not sufficient by ninety feet to reach the passage through the Port Neuf River into the Snake. This first rise was followed by a long epoch of desiccation, during which it is probable the lake entirely disappeared. This inter-lacustrine epoch was a long one, as is indicated by the extent of the gravel deposits which were then laid down. After this there was a second rise, in which the water attained the height of the passage from the Cache Valley to the Port Neuf, and then rapidly "cut a channel three hundred and seventy-five feet deep in the alluvium to a sill of limestone." At this level (about six hundred feet above the Great Salt Lake) the water was held for a long time, forming what is known as the Provost shore-line. During the period of the Provost shore-line, glaciers descended from the Wahsatch Mountains, and left their moraines near the margin of the lake.

In searching for an explanation of the former increase in size of these bodies of water, the conditions of the Glacial period naturally present themselves as furnishing an adequate cause. Glaciers, however, never occupied much of the territory, being found only to a limited extent in the bordering mountain-ranges. But the proximity of the glaciated region, and, indeed, the general conditions favoring the production of the Glacial period in North America, would be ample to produce the temporary enlargement of these lakes. A slight increase in precipitation, or a slight diminution of temperature, would either of them cause a rise in the water until the balance should be readjusted between the rainfall and the evaporation.

It would seem that there is here also a significant record of an interglacial epoch, for the lakes have had two periods of increase, with an arid period intervening. During the first rise of the lakes, sediment to the extent of one hundred and fifty feet in thickness was deposited. There was then a dry period, in which the lakes were reduced to their present dimensions, or even smaller, when these first deposits were subjected to a period of erosion by surface streams, and partly covered with gravel. There was also upon it a deposit of great quantities of compact stony tufa precipitated from waters saturated with calcium carbonate. After the period of low water there was a subsequent reflooding of the basin. which reached a horizon thirty feet higher than the first. During this rise a deposit of thinolite took place, and of other substances whose position and character serve to note the changes. Subsequent to this rise the evaporation proceeded at an increased rate until the basins were completely desiccated, and only began to refill within a period which Mr. Russell estimates to be less than three hundred years. All this, however, might have occurred within the space of a few thousand years, and does not, independently of other evidence, go far to establish the complete duality of the Ice age.

As to the date of the expansion of these lakes, Mr. Russell expresses it as his opinion that "the last desiccation oc-

curred certainly centuries, but probably not many thousands of years ago." * This opinion is sustained by the fact that the erosion of present streams in these old beds is slight, and by the fact that in the cañons of the high Sierra, which were once occupied by glaciers, "the smooth surfaces are still scored with fine, hair-like lines, and the eye fails to detect more than a trace of disintegration that has taken place since the surfaces received their polish and striation. . . . It seems reasonable to conclude that in a severe climate like that of the high Sierra it [the polish] could not remain unimpaired for more than a few centuries at the most." To the same effect is the testimony of Mr. Gilbert as to the date of the last great extension of Lake Bonneville, of which he says: "The Bonneville shores are almost unmodified. Intersecting streams, it is true, have scored them and interrupted their continuity for brief spaces; but the beating of the rain has hardly left a trace. The sea-cliffs still stand as they first stood, except that frost has wrought upon their faces so as to crumble away a portion and make a low talus at the base. The embankments and beaches and bars are almost as perfect as though the lake had left them yesterday, and many of them rival in the symmetry and perfection of their contours the most elaborate work of the engineer. There are places where bowlders of quartzite or other enduring rock still retain the smooth, glistening surfaces which the waves scoured upon them by dashing against them the sands of the beach.

"When this preservation is compared with that of the lowest tertiary rocks of the region—the Pliocene beds to which King has given the name Humboldt—the difference is most impressive. The Pliocene shore-lines have disappeared.

"The deposits are so indurated as to serve for building-stone. They have been upturned in many places by the uplifting of mountains. Elsewhere they have been divided by faults, and the fragments, dissevered from their continuation in the valley, have been carried high up on the mountain

* "Monograph XI," p. 273.

flanks, where erosion has carved them in typical mountain forms. . . . The date of the Bonneville flood is the geologic yesterday, and, calling it yesterday, we may without exaggeration refer the Pliocene of Utah to the last decade the Eocene of the Colorado basin to the last century, and relegate the laying of the Potsdam sandstone to prehistoric times."*

Mr. Gilbert believes that all this is attributable to successive elevations of the region, with an intervening subsidence. The evidence of a post-tertiary elevation is found "in the deeply submerged channel near Cape Mendicino," while the proofs of a subsequent depression "are supplied by the marine terraces of the Columbia and Fraser basin, and by the post-tertiary beds of the California coast recently described by Dall as rising gradually toward the south until at Monterey and southward they are about six hundred feet above the sea-level. . . . The uplifting of the Wahsatch range is shown to be still in progress by post-Bonneville fault-scraps." Mr. Gilbert's study of the horse-remains found in the region would assign them to the period of "the uppermost of the Lahontan and Bonneville beds," thus transferring their geological horizon from the late tertiary to the latter part of the glacial period.

It is interesting to note, in connection with these old lake-basins, that the Dead Sea in Palestine probably has a similar relation to the development of glaciers in the Lebanon Mountains, and Russell is of the opinion that the gravel-deposits reported at various elevations about it are, like those of Lakes Bonneville and Lahontan, records of the Glacial period.†

My own investigations upon the glacial deposits of the Lebanon Mountains, however, showed that there had never been any glaciers reaching the head-waters of the Jordan Valley; but there was a glacier descending from the highest

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*"Second Annual Report of the U. S. Geological Survey," p. 188.

†"Jordan-Arabah and the Dead Sea, "Geological Magazine," vol. 5, pp. 337, 387.

summit of the mountains about thirty miles northeast of Beirut and depositing an extensive moraine upon which the present grove of the Cedars of Lebanon are growing. The height of the summit is a little over 10,000 feet, and the glacier descended to the level of 5,000 feet above the sea. The moraine is about three miles broad at the foot, and extends five miles back toward the summit, and is several hundred feet thick at its termination. Though not directly connected with the Jordan Valley the climatic conditions accompanying the formation of this glacier doubtless extended a long distance in that direction and so may account for the enlargement of the Dead Sea indicated by the abandoned shorelines, the most persistent of which is 650 feet above its present level. (See "Records of the Past," July, 1906, pp. 195-204.)

Such are, in brief, the considerations which seem to make it proper to hesitate before recognizing the theory of discontinuous pleistocene epochs in America as an established doctrine to be taught. The most of the facts adduced to support the theory of distinct epochs are capable of explanation on the theory of but one epoch with the natural oscillations accompanying the retreat of so vast an ice-front. It seems more likely that the retreat from the extreme border of the glaciated area to the line of the moraines of the several later glacial epochs was analogous to that from one to another of the successive twelve or thirteen receding concentric lines of moraine appearing on our general map and on that of Minnesota made from the latest reports, than that successive glacial advances should so nearly duplicate the first as it is made to do on the other theory.

After a pain-staking discussion of the whole subject, Professor Prestwich expresses it as his opinion that —

The time required for the formation and duration of the great ice-sheets in Europe and America (the Glacial period) need not, after making all allowances, have extended beyond fifteen thousand to twenty-five thousand years, instead

of the one hundred and sixty thousand years or more which have been claimed.

The adoption by some of a term of eighty thousand years for the post-Glacial period has been very much the result of the belief that no shorter time would account for the excavation of the valleys supposed to have been formed during this period, on the assumption of a "uniformitarian" rate of denudation. This rate, based on observations made at the present time, always seemed to me open to grave objections, and in this belief subsequent experience has confirmed me. . . . and I would for the same reasons limit the time of the so-called post-Glacial period, or of the melting away of the ice-sheet, to from eight thousand to ten thousand years or less.*

Summary. — The terrestrial facts brought to light as clearly bearing on the question of the date of the glacial era are much more numerous than they have heretofore been supposed to be. Scarcely more than a beginning has been made in their collection and interpretation; but, as far as we have gone, the investigation has been most interesting and suggestive. For the most part these facts imply a later date for the Glacial period than the current astronomical theory would admit, and so far they go to disprove that theory.

The glaciated area seems a vastly newer country than the unglaciated. In the glaciated region the waterfalls have hardly more than begun to recede; the valleys and gorges are both narrower and shallower than in the unglaciated portion of the country; the lakes and kettle-holes are yet unfilled with sediment, and their outlets have not yet to any great extent lowered the drainage lines; the striated rocks have resisted disintegration to a remarkable degree during post-glacial times, and the moraines and kames have retained their original forms with little signs of erosion. Niagara Falls and the Falls of St. Anthony can neither of them be over ten thousand years old. The waves of Lake Michigan can

* See Prestwich's "Geology," vol. ii, pp. 533, 534.

not have washed its shore for a much longer time, and the smaller lakes and kettle-holes of New England and the Northwest can not have existed for the indefinite periods sometimes said to have elapsed since the glacial era, while eternity itself is scarcely long enough for the development of species if the rate of change is no greater than is implied if man and his companions both of the animal and vegetable kingdom were substantially what they are now as long ago as the date often assigned to the great Ice age.

But while approximate limits are already set to glacial chronology, the field is still open for an indefinite amount of painstaking inquiry. Local observers may now profitably spend as much time upon a single river-valley or in a single county as has yet been spent upon the whole field between Cape Cod and the Mississippi.

FIG. 156—Bowlder bed at Pocatello, Idaho, where the Port Neuf river debouches upon the Snake river plain. These bowlders were brought down to their present position by the torrential floods which followed the overflow of Lake Bonneville, described on pages 609 and 704

CHAPTER XXI.

MAN AND THE GLACIAL PERIOD.

WHEN, in 1863, Sir Charles Lyell published his great work upon "The Antiquity of Man," the general public was somewhat surprised to find that one hundred and sixty pages, or almost one third of the entire volume, was devoted to a discussion of glacial phenomena. This course was justified by the fact that rough-stone implements, undoubtedly of human manufacture, had recently been found in deposits supposed to be of glacial age in northern France and southern England, making the question of the antiquity of man one no longer of mere history or archæology, but of glacial geology. A further reason for the prominence given to the discussion of purely glacial questions in Sir Charles Lyell's work was the comparative ignorance, at that time, of the character, extent, and significance of glacial phenomena. The discussions running through the previous

FIG. 157.—Typical collection of palæolithic implements, reduced in photograph to one eighth natural size. The four in the lower row are of argillite from the gravel in Trenton, New Jersey. The small one, a little above the lower row is from Moustier, France. The large one in the middle row is from Amiens, France. The two at the left of it are from France. The one at the right is from upper Egypt. These are all of flint. The four in the upper row, a core of flint and flakes of flint.

chapters of the present volume prepare the way for readily understanding even a summary statement of the facts already discovered connecting man with the Glacial period in North America. We may, therefore, without further preliminaries, at once address ourselves to the subject, and describe the conditions in which implements of human manufacture have been found in the glacial deposits on this continent.

FIG. 158.—Reverse side of the implements shown in the preceding figure.

At the outset two questions arise in the discussion: 1. Whether the implements found are really artificial and genuine. 2. Whether the deposits in which they occur really belong to the Glacial period.

1. That the implements are of human origin is evident from close inspection, and comparison with natural fragments. Flint and some other species of stone are specially adapted for the manufacture of implements, because of their hardness, and of the facility with which flakes can be struck from them so as to leave a sharp, cutting edge. Many natural forms of flint can be appropriated as useful tools without modification. The action of frost upon a flint nodule, or the accidental falling of a stone upon it, may produce a sharp-edged fragment of convenient size for use. But the proof of human workmanship consists in a series of fractures of such character and so arranged that they irresistibly indicate design. One prominent feature of an artificial flake is

the so-called "bulb of percussion." When a sharp, well-directed blow falls upon a flint nodule, the force distributes itself in such a way that, in the immediate vicinity of the blow, a slight hollow is made in the nodule, and the corresponding bulb in the flake is shaped somewhat like the ball of one's thumb, while the rest of the flake is straight and regular in form. It is possible that this bulb of percussion may sometimes be made by the accidental falling of one stone upon another; but such an occurrence must, in the nature of the case, be very rare, since the blow must be delivered at exactly the right point and at the proper angle, in order to produce the right result. The chances are exceedingly small that such a blow should be delivered except by design.

As to the arrangement of the fractures, the evidence is even more conclusive. A simple cutting edge may readily be formed by natural forces; but, in the implements that are regarded as of human origin, the arrangement of the fractures producing the cutting edge is so complicated as to preclude the supposition that they are undesigned. Nor does it require many secondary chippings to establish the artificial origin of an implement. A half-dozen subsidiary chippings on a natural flint pebble, serving to bring it into a symmetry such as would serve the purpose of a human being, is evidence enough. A trained eye has no difficulty in distinguishing, at a glance, between natural forms and artificial forms. The loose statements asserting that there is occasion for grave doubt as to whether the mass of so called palæolithic implements are really implements can only be made, and be believed, by those who have given little personal attention to the subject.

That I may not seem to place too much confidence in my own judgment in this all-important matter, I have thought it best to secure the opinion, concerning the implements of which this chapter treats, of one who has had ample opportunity to examine them and compare them with those from other parts of the world, and whose authority would be second to that of none. I therefore addressed a letter

to Professor Henry W. Haynes, of Boston, requesting his opinion on the subject. His reply I will, with his consent, reproduce.*

BOSTON, *January 23, 1889.*

DEAR PROFESSOR WRIGHT: You ask for my opinion in regard to the artificial character of the quartz fragments discovered by Miss Babbitt, at Little Falls, Minn., as well as of the argillite objects discovered by Dr. Abbott, at Trenton, N. J., and those still more recently obtained by Dr. Metz and Mr. Cresson. In replying to your inquiry I must premise by stating that, although I have had abundant opportunity of studying all these different objects, I have only visited one of the localities where they were found—that is Trenton, N. J.—where, as you know, I was accompanied by yourself, Professor Boyd Dawkins, and the late Professor Henry Carvill Lewis, in my examination of the region; but I had previously visited many localities in Europe, where palæolithic implements have been discovered; and I have myself found many. Several years of study in that country have made me familiar with the cleavage of flint, and the method of fabricating rudely chipped implements. Subsequently, in this country, for a still longer period, I have given much attention to the tools and weapons of the Indians, and the different materials of

* I would remark that Professor Haynes's private collection of palæoliths is one of the largest in this country, and abounds in representatives from every locality where they have been found. The following is a list of his publications upon the subject: Silex Acheuléens de l'Egypte, "Bull de la Soc d'Anthrop de Paris," 3d ser., vol. i, p. 339; "The Fossil Man," "Popular Science Monthly," July, 1880, p. 350; "The Egyptian Stone Age," "Nation," January 27, 1881; "Discovery of Palæolithic Implements in Egypt," "Memoirs of the American Academy of Arts and Sciences," vol. x, p. 357; "The Argillite Implements," etc. "Proceedings of the Boston Society of Natural History," vol. xxi, p. 132; "The Palæolithic Man," "American Antiquarian," vol. vi, p. 137; "The Stone Age in Prehistoric Archæology," "Science," vol. iv, pp. 469, 522; "Man in the Stone Age," "Science," vol. v, p. 43; "The Bow and Arrow unknown to Palæolithic Man," "Proceedings of the Boston Society of Natural History," vol. xxiii, p. 269; "Palæolithic Man in London and its Neighborhood," "Science," vol. ix, p. 221; "Opinion on Palæolithics," "American Antiquarian," vol. x, p. 125; "The Prehistoric Archæology of North America"; "Narrative and Critical History of America," vol. i. pp. 329–368.

which they were fashioned, in a great many different localities. I think, therefore, I have gained an acquaintance with the character of the fracture of very many different kinds of stone, which have been broken by man intentionally for his use as tools. I say this, because I have always been in the habit of comparing and contrasting such broken stones with those whose fracture had been occasioned by different natural forces, so that I might learn the resemblances and the differences between them. This is a subject which it is difficult to treat of satisfactorily in writing, as it is so much an affair of ocular demonstration. These little minute differences and peculiarities are very palpable, when they are pointed out, although a geologist, or a mineralogist, who is perfectly familiar with the material, but who may have had little or no training as an archæologist, may have failed to notice them. The whole subject is one solely for the judgment of the expert; and when a heap of broken stones, characterized by a general external resemblance, has been submitted to the determination of several trained archæologists, as I have often seen done in Europe, there has been no difference of opinion among *them* as to which were natural and which were artificial forms. Of course, if the broken stones have been afterward subjected to the action of running water, so as to produce a general wearing away of the edges of the fractures, the difficulty of discriminating becomes much greater. In such cases only a very practiced eye can decide, and the opinion of any man, however eminent he may be in other departments of knowledge, who has not had great archæological experience, is practically worthless.

It was in the autumn of 1880 when we visited Trenton, and at that time I found a few palæoliths there myself; afterward Dr. Abbott gave me quite a collection of his own finding, which I have had ever since in my possession, and have continually studied. So in repeated instances have I examined his great collection in the Peabody Museum. At a meeting of the Boston Society of Natural History, in January, 1881, I expressed my conviction as to the artificial character of these argillite implements, notwithstanding the fact that the coarseness of their material precludes their ever equaling in workmanship the flint implements of Europe. My subsequent

study of the same and other objects from that locality has only served to strengthen the opinion I then expressed.

The quartzes discovered by Miss Babbitt I first saw in the autumn of 1882, when she forwarded a box of them for my inspection. The following summer she sent me another lot of them on deposit; both of these have been in my possession ever since, and have been repeatedly studied by me. I have also examined the collection she sent to the Peabody Museum. I should judge that I have thus had at least a hundred and fifty of these pieces of quartz brought under my careful scrutiny. Miss Babbitt had no knowledge of archæology, and her fanciful speculations in regard to the supposed use that had been, or might have been, made of certain fragments, which she dignified with the name of types, have tended to obscure the real presence among them of some well-marked examples of palæolithic implements. I wrote her my opinion in regard to them, and a portion of my letter was printed by her in connection with her articles on "Vestiges of Glacial Man in Minnesota," in the June and July numbers of the "American Naturalist" for 1884. In this I stated that "some of them I believe to be implements; many are only chips struck off in shaping implements, and refuse pieces left from such work; many are natural forms, and one or two rolled pebbles. . . . I trace clearly upon your implements such a preparation of them (i. e., by having had most of their projections battered off by another stone) for holding them in the hand. Many of yours bear evident marks of use in the worn condition of portions of their edges or of their points." All my subsequent study of them has tended to confirm this opinion, and I can only repeat my assured conviction that these rudely fashioned implements, and the fragments that were found with them, whose edges are still as sharp as when they were first struck off, are the "product of an intentional breaking by the hand of man and not the result of natural causes."

It is important to notice that among the hundreds of palæolithic implements discovered by Dr. Abbott, at Trenton, a few made of quartz are so absolutely similar to those found by Miss Babbitt, and now either in my possession or at the Peabody Museum, that it would be impossible to distinguish them apart.

The implements discovered by Dr. Metz and Mr. Cresson, and now also in the Peabody Museum, are as palpable human tools as any I ever saw, although, on account of the inferior quality of the material of which they are made, they are not equal in excellence to similar objects of like age in Europe. I can not conceive of any one, who has a proper acquaintance with the subject, entertaining a moment's question as to their artificial character.

By this frank expression of my conviction, I have endeavored, as best I can, to answer your questions, and remain,

Sincerely yours,

HENRY W. HAYNES.

A still further question with regard to these implements relates to their genuineness. Their present commercial value offers temptation for their forgery, and there can be no doubt that hundreds of implements of the very earliest type have been made to order and sold to unsuspecting collectors. Still, however perfect these forgeries may be in form, only the inexperienced and the unwary can be deceived by them. There are certain chemical changes affecting the superficial aspect of an implement which time only can produce. A fresh flake can readily be distinguished by a practiced eye. As yet not enough is known of the rapidity with which weathering takes place under stated conditions, to make it a basis for chronological calculation; but the difference between a very ancient implement and a very recent one is easily enough detected. It is a significant fact early observed, and supported by all recent discoveries (if we except those in California, of which further mention will be made), that in America as in Europe the implements found in glacial deposits are all of a peculiar type. None but implements of stone have been found in these deposits; and of the stone implements none are polished and smooth, but all are rude in form and roughly flaked. From their evident antiquity, as will be shown a little later, these rough stone implements are called *palæolithic* (Gr. παλαιός "old," and λίθος,

"stone"); while the later stone implements are classified as *neolithic* (Gr. *νέος*, "new," and *λίθος*, "stone").

Palæolithic implements are said to be old, however, not because of any inelastic theory of evolution, implying that people using rude arts always precede those who are more skilled, but the age of these implements as a class is determined by the fact that they have been found in undisturbed glacial deposits or under other geological conditions showing their antiquity. Such implements are unquestionably older than others found upon the surface; and, in their case, the evidence of great age is definite and conclusive, while the antiquity of the implements found upon the surface is subject to more or less of doubt. If man inhabited the region bordering upon the great ice-sheet when it extended to its farthest limits, his implements should be found near the surface of the ground outside those limits; and such might be of even greater age than those which are found in stratified glacial deposits themselves. Also, as the ice receded, it is to be expected that man would follow it in its slow recession (as the Eskimo does to-day in Greenland) and that his implements would be lost upon the surface. How long he may have continued thus to use implements of palæolithic type can not readily be determined. Mr. Thomas Wilson, of the Smithsonian Institution, has already collected, or had reported to him, many thousand implements of the palæolithic type found in various parts of North America. In almost all cases these were found upon the surface, and there is no means of determining their age except from their general weathered appearance, as implements of the same forms have been made and used all through the Stone age.

About the year 1860 interest in the subject of man's antiquity received a new and definite impulse in connection with the discoveries of Boucher de Perthes in northeastern France. As long ago as 1841 this indefatigable investigator discovered rudely fashioned stone implements in high gravel terraces along the valley of the Somme at Abbeville. An account of his discoveries was published in 1846. Little at-

tention was paid to the matter, however, until 1859, when Dr. Falconer, Mr. Prestwich, Mr. Evans, Sir Charles Lyell, and other English geologists visited the locality, and brought the discovery more fully to public attention. Full descriptions may be found in the works of Sir Charles Lyell on "The Antiquity of Man" * and Sir John Lubbock on "Prehistoric Times." †

The river Somme is a small stream, about one hundred miles in length, occupying a broad, deep trough, about a mile in width at Abbeville, worn out of chalk formations. Upon the sides of this trough, up to an elevation of something over one hundred feet, there are remnants of gravel terraces, formed when the river flowed at a correspondingly higher level than now. These terraces consist wholly of material local to the Somme Valley, and not in any degree of foreign drift. The implements found are imbedded in undisturbed strata of this gravel. In connection with them, also, there are found bones of many animals now extinct, those of the *Elephas primigenius* being specially numerous.

Soon after the confirmation by these eminent authorities of the important discoveries made by Boucher de Perthes, examination showed that the same class of rudely formed chipped stone implements occurred also in gravel-deposits in southern England. The relation of these deposits to the streams was similar to that of those in the valleys of northeastern France. Indeed, a discovery of palæoliths had been made in England more than fifty years before, in the very first years of the century; but its importance was not suspected until Boucher de Perthes's discoveries called attention anew to the subject. Mr. John Frere had, in the year 1800, described a collection of flints found at Hoxne near Diss, in Suffolk, England, specimens of which were preserved in the British Museum and in the collections of the Society of Antiquaries. These proved to be of the same type with those found at Abbeville, and the deposits are of corresponding

* P. 106 *et seq.*

† P. 342 *et seq.*

character in the two places. Similar discoveries were also made at various other places in southeastern England, the most important being in the vicinity of Southampton and the Isle of Wight.

When we come to examine these European deposits with reference to their relation to the Glacial period, it must be confessed that we enter a rather obscure field. The region in Europe in which palæolithic implements have been found imbedded in the gravel of river terraces is peculiar for its limitation. In Great Britain none have been found north of a line connecting the British Channel with the Wash, and on the Continent these discoveries are all outside the direct action of glaciers either from the Scandinavian or the Swiss fields. Hence it will be seen that the problem is quite different from that which we shall presently study in America, and is far more complicated. Still, the same rule holds good in one country as in the other, that the higher terraces are older than the lower, and there can be little doubt that the terraces in which palæoliths are found are directly or indirectly of glacial origin. But the data for estimating the time which has elapsed since the deposition by glacial torrents of the high-level gravels in the valley of the Somme and in southern England are much less clear than in this country.

The year 1875 marks an epoch in the prehistoric archæology of North America, since it was then that Dr. C. C. Abbott's attention was first specially attracted to the implements of a palæolithic type found in the neighborhood of his residence in Trenton, N. J. Whether these implements were from the surface, or from the gravel which underlies the city, was at first uncertain, for they had then been found only in the talus of the gravel-banks. But Dr. Abbott's residence at Trenton enabled him during the succeeding year to give attention to the numerous fresh exposures of the gravel made by railroad and other excavations; and he was soon rewarded for his pains by finding several chipped implements in undisturbed strata of gravel, some of which were as

much as twelve feet below the surface. Since that time he has continued to make similar discoveries at various intervals. In 1888 he had already found four hundred implements of the palæolithic type at Trenton, sixty of which had been taken from recorded depths in the gravel, two hundred and fifty from the talus at the bluff facing the river, and the remainder from the surface, or derived from collectors who did not record the positions or circumstances under which they were found. In 1878 Professor J. D. Whit-

Fig. 159.—Face view of argillite implement, found by Dr. C. C. Abbott, in 1876, at Trenton, New Jersey, in gravel, three feet from face of bluff, and twenty-two feet from the surface (No. 10,985). (Putnam.)*

* This cut, together with the following ones credited to him, Professor F. W. Putnam has kindly furnished me, for use in advance of publication, from his elaborate report upon the palæolithic implements in the Peabody Museum of American Archæology and Ethnology, Cambridge, Mass. The numbers in parentheses are those on the implements, and correspond to the catalogue of the museum. The figures are natural size.

ney, with Mr. Lucien Carr, of the Peabody Museum, Cambridge, visited Dr. Abbott, and they together found several palæolithic implements in the undisturbed gravel.* And again, in 1879 and 1880, Professor F. W. Putnam was with Dr. Abbott when specimens were found in similar conditions. Mr. Carr describes the situation as follows: It was "in a fresh exposure made by a recent heavy storm, and was about three feet deep in the ground, and one foot in from the perpendicular face of this newly exposed surface." Professor Putnam gives the following description of his discoveries:

Fig. 160. Side view of the preceding. (Putnam.)

A short distance from Dr. Abbott's house, and very near where the Trenton gravel joins the marine gravel, there is a deep gully through which flows a small brook. In this gully the gravel-bank is constantly washing away, and presenting new surface exposures. After a heavy rain in June, 1879, I visited the spot with Dr. Abbott and his son. Here I noticed a small bowlder of about six or eight inches in diameter, projecting an inch or two from the face of the bank about four feet from the surface of the soil above; I worked the stone from the gravel in which it was firmly imbedded and drew it out. At the back part of the cavity thus made I noticed the pointed end of a stone, and

* "Proceedings of the Boston Society of Natural History," vol. xxi, p. 145.

after working it up and down a few times, so as to loosen the gravel about it, I drew out the implement now exhibited.

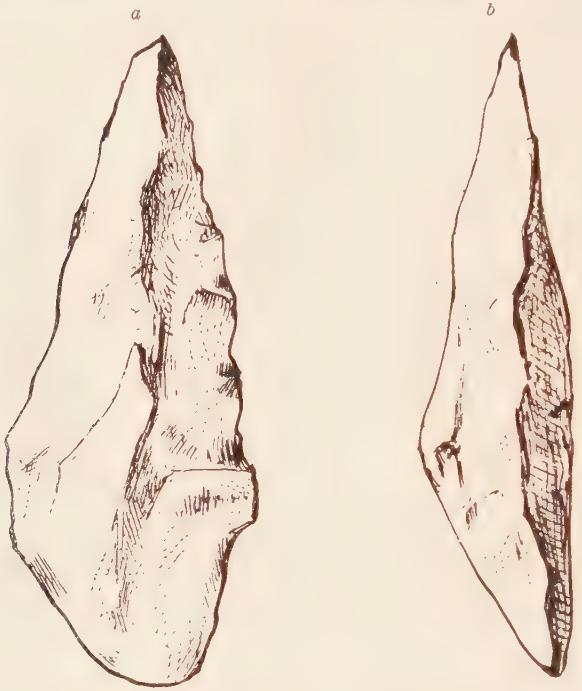

FIG. 161.—Argillite implement found by Dr. C. C. Abbott, March, 1879, at A. K. Rowan's farm, Trenton, New Jersey, in gravel sixteen feet from surface. *a*, face view; *b*, side view. (No. 11,286.) (Putnam.)

On the same day I discovered a second specimen in place eight feet from the surface, and Dr. Abbott's son Richard found another about four feet from the surface. These three specimens were found within twenty or thirty feet of each other, after a heavy shower had made the most favorable conditions for their discovery.

My own first visit to the locality was in November, 1880, in company with Professors W. Boyd Dawkins, Henry W. Haynes, and H. Carvill Lewis, when we were conducted by Dr. Abbott to the various localities favorable for investigation. Professor Lewis and myself also repeatedly visited the

locality afterward. But neither of us was ever so fortunate as to find a palæolithic implement in place, or even in the fresh talus of the bluff facing the river. As our experience is that of many others who have visited the locality, and hence of attempts in some quarters to throw doubts upon the genuineness of Dr. Abbott's discoveries, it is worth while to record that Professors Dawkins and Haynes independently

Fig. 162. Chipped pebble of black chert, found by Dr. C. C. Abbott, 1876, near the site of Lutheran church, Trenton, New Jersey, in gravel six feet below the surface. *a*, face view: *b*, side view. (No. 10,986.) (Putnam.)

found implements in the talus over which we had passed a moment or two before; but, as the attention of Professor Lewis and myself was directed chiefly to the geological problems relating to the character and age of the deposit itself, our failure to discover implements where trained eyes saw them but illustrates the limitations of observers. To distinguish a roughly flaked human implement in a bed of gravel and pebbles where the ratio of artificial flakes to the natural forms is as one to a million, is like finding a needle in a haymow. Hence negative evidence, or a failure of particular

observers to find implements, has very little weight in discrediting the testimony of others who have been more successful.

The acrimonious controversy over the genuineness of these implements of supposed glacial age was finally put to rest by a fortunate discovery made by Mr. Ernest Volk, while working under the auspices of the Peabody Museum of Cambridge, Mass. The discovery was that of a human femur, in undisturbed gravel twenty feet below the surface, and beneath a thick deposit of crossbedded coarse gravel which unquestionably belongs to the glacial era. The accompanying illustration of the gravel pit in which this was found lies in the same bank shown in the illustration on p. 521, but after the gravel bank had been excavated 100 feet or more farther back from the river.

Accepting as now beyond question that these palæolithic implements at Trenton occur in undisturbed strata of the gravel, of which the evidence just given would seem to be sufficient, the question of the archæologist as to the age of the deposit is asked of the geologist, and it is for him to answer. In the light of the preceding chapters, a ready answer is found to this question. The city of Trenton is built upon a horseshoe-shaped gravel-deposit which is about three miles in diameter, extending back about that distance to the east from the present river. This deposit is somewhat lower around its inland boundary than along the river. The prongs of this horseshoe rest, one at Trenton, and the other two miles below, just north of the house of Dr. Abbott. This gravel is thus described by Professor Shaler:

The general structure of the mass is neither that of ordinary bowlder-clay nor of stratified gravels, such as are formed by the complete rearrangement by water of the elements of simple drift-deposits. It is made up of bowlders, pebbles, and sand, varying in size from masses containing one hundred cubic feet or more to the finest sand of the ordinary sea-beach-

Fig. [illegible].—Typical section of the Trenton gravel in which the implements described in the text are found. Note the distinct stratification and the large angular bowlder near the surface, showing the presence of floating ice, since by no other means could such a bowlder get into such a position as here found. The elevation of the section here figured is about half a mile back from the river edge of the bluff. Perpendicular exposure is here between 30 and 40 feet.

(Photograph by Abbott.)

es. There is little trace of true clay in the deposit ; there is rarely enough to give the least trace of cementation to the masses. The various elements are rather confusedly arranged ; the large bowlders not being grouped on any particular level, and their major axes not always distinctly coinciding with the horizon. All the pebbles and bowlders, so far as observed, are smooth and water-worn, a careful search having failed to show evidence of distinct glacial scratching or polishing on their surfaces. The type of pebble is the subovate or discoidal, and though many depart from this form, yet nearly all observed by me had been worn so as to show that their shape had been determined by running water. The materials comprising the deposit are very varied, but all I observed could apparently with reason be supposed to have come from the

Fig. 164—Gravel deposit at Trenton, N. J., where Mr. Volk found a human femur in December, 1899. The arrow points to the spot where the femur was discovered. (Courtesy of Records of the Past.)

extensive valley of the river near which they lie, except perhaps the fragments of some rather rare hypogene rocks.*

It is now settled that the rocks from which these beds were derived are all in place in the upper Delaware Valley.†

The distinction between the river-gravel and that which overlies the larger part of southern New Jersey is marked in several ways. The Trenton gravel is much coarser than the general deposit, it is also largely composed of fresher looking and softer pebbles, showing that it has been subject to much less abrasion than the other, and that it is of more recent age; it is also limited to the river-valley, and finally is not overlaid by the Philadelphia brick-clay which, so far as it extends, rests unconformably upon the general deposit of gravel. The general deposit of gravel in this region is composed almost exclusively of small, well-rounded pebbles of quartz and of hard limestone which "are not fresh looking, but are eaten and weather-worn by age."

FIG 128. Section across the Delaware River at Trenton, New Jersey. *a, a*, Philadelphia red gravel and brick clay (McGee's Columbia deposit); *b, b*, Trenton gravel, in which the implements are found; *c*, present flood plain of the Delaware River. (After Lewis, in Abbott's "Primitive Industry.")

The elevation of this implement-bearing gravel at Trenton is not far from forty feet above the present high-water limit; and Trenton is now at the head of tide-water. These gravels are continuous as a terrace all along up the river. As one ascends the river, however, their height (at least below the Water-Gap) is reduced to fifteen or twenty feet above the present flood-plain.

But most significant of all the facts indicated are the character and position of the Philadelphia red gravel and brick-clay. This also is confined to the river-valley and its tributaries, and rests unconformably upon the older gravel

* "Report of Peabody Museum," vol. ii, 1876-'79, pp. 44-47.

† "New Jersey Report for 1877," p. 21; Lewis on "The Trenton Gravel," p. 5.

formations, rising to a height of one hundred and fifty feet above the river, and there ceasing. This elevation relative to the river is maintained as far up as Easton, where the bed of the river itself is one hundred and fifty-seven feet above tide-level. Finally, the Philadelphia brick-clay contains numerous bowlders of considerable size, derived from the ledges of Medina sandstone and other rocks above. This marks it as a deposit of the glacial flood some time during the declining centuries of the great Ice age.

The succession of events would seem to be as follows: During the early part of the Glacial period the ice accumulated in the upper portion of the valley of the Delaware to a depth of many hundred feet. The area in the valley of the Delaware covered by the ice is not far from six thousand square miles. It is not improbable that the average depth of the ice accumulated over the region was considerably more than fifteen hundred feet, or a quarter of a mile, making the total accumulation of ice more than fifteen hundred cubic miles, with its southern border sixty miles above Trenton. All this as it melted must find its outlet to the sea through the Delaware River. It is evident at a glance that during the decline of the Glacial period, when the process of melting was proceeding with greatest rapidity, the floods in the valley below must have been upon a scale of surprising magnitude.

And yet it is impossible that these glacial floods in the Delaware should have been so enormous as to have filled the valley below Trenton to the height of one hundred and fifty feet, for this valley is nowhere less than five miles in width and constantly enlarges toward the sea. If the water at Trenton were raised one hundred and fifty feet, the slope to the bay would be about two feet per mile. Now, a current of five miles per hour, one hundred and fifty feet deep and *one* mile wide, would discharge a cubic mile of water every eight hours, or three cubic miles per day. (The mean rate of the Ohio River, with an average descent of five inches to the mile, is three miles per hour—that of the Mississippi

very nearly the same.) To supply such a volume of water as this, the whole accumulation of ice in the upper Delaware would suffice for only five hundred days, or for about sixteen months. And to furnish this amount of water there would need to be, during such floods, a daily accumulation by rains and the melting ice over the whole upper valley of the Delaware of about three feet of water, which of course is incredible, even if we suppose the floods confined to a single month of each successive year. Hence, without doubt, we may conclude that the deposition of the bowlder-bearing brick-clay in the Delaware Valley below Trenton implies a depression of that region to the extent of one hundred or more feet.

Doubtless the region north of Trenton shared in this depression, but, being above the tide-water, the effects would not be equally evident. The valley above Trenton is narrow; at Lambertville, about twelve miles up the stream, a trap-dike contracts the valley to a width of about one quarter of a mile. Above this point the supposition of floods sufficient to deposit the bowlder-bearing clay is, therefore, not incredible, especially since the descent in the stream was probably less then than now. For the depression of that period proceeded, as we have seen, at increased rate northward. In Montreal, it was five hundred feet; in Vermont, about three hundred feet; and how much more or less in the vicinity of Lake Erie we can not tell. Such depression would greatly diminish the velocity of the torrent, and the narrow places in the valley would work to the same end. Professor Dana has shown that in the lower part of the valley of the Connecticut River the floods rose during the Champlain epoch from one hundred and fifty to two hundred feet above the present high-water mark. But the Connecticut River Valley below Middletown is contracted by trap dikes much as the Delaware is at Lambertville; and the drainage basin of the Connecticut is three times as extensive as that of the Delaware (being twenty thousand square miles). The effect of this obstruction, however, is partly offset by the branch currents which, as Professor Dana shows, set off from the Connecticut at various places above Middletown.

After an exhaustive examination carried on for several years in connection with the New Jersey Geological Survey, Professor Salisbury reports finding deposits in that state corresponding to those here spoken of as Philadelphia brick clay and red gravel, which he describes under the local names of Bridgeton and Pensauken, reaching a height of 200 feet in the case of the former and 150 of the latter. But he is inclined to refer these "in large part to subaërial (fluvial and pluvial origin"). On this theory the deposits were chiefly brought into place by the Delaware and its tributaries during the close of the first glacial period, when the land was nearly at its present level, and the streams were overloaded with glacial débris. This accumulated as a broad delta over lowlands which were subsequently so much eroded that only the present remnants are left.

But the extent over which the deposit is spread, as well as its character militates strongly against this theory. For the deposit extends for many miles northeast of the Delaware at Trenton, above where the unaided current of the glacial stream would carry the material, while several miles southeast of Trenton, bowlders, three and four feet in diameter, are found at an elevation of 200 feet, the bowlders being identical in material with others bearing glacial scratches found in the valley of the Delaware, twenty or thirty miles above Trenton. It hardly is possible that the whole area south of Trenton to the limit of these bowlders was covered with Bridgeton gravel to this height, Besides, the distribution of the bowlders in the brick clays of Philadelphia was evidently by stranded icebergs. In this clay bowlders two and three feet in diameter are distributed in a manner that would be impossible in any other way. A depression of 200 feet in the lower valley of the Delaware, therefore, cannot easily be dispensed with. Similar facts lead to the same conclusion respecting the depression at the mouth of the Susquehanna at the head of Chesapeake Bay, near Havre de Grace.

At any rate, in the Delaware Valley we find bowlder-bearing clay rising to a height of one hundred and fifty or more feet above the present high-water level. In the Lehigh Valley, at Bethlehem, a few miles above its junction with the Delaware, and several miles south of the limit of the ice-field, Professor Lewis and myself found this bowlder-bearing clay containing scratched pebbles and lying unconformably upon thick deposits of coarse stratified gravel at a height of one hundred and eighty feet above the river. Farther up the Lehigh Valley also, near Weissport, we ascertained the limit of ice-carried bowlders to be one hundred and eighty feet above the river.

We are probably safe in assuming that these floods, depositing clay and bowlders at the height above mentioned, mark both the period of greatest depression during the Glacial epoch and that when the ice was most rapidly melting away. Of course, the deposition of what Professor Lewis styles "red gravel," and the high gravels at Bethlehem, occurred earlier, since the clay overlies them.

It is evident that the deposition of this bowlder-bearing clay is separated from that of the implement bearing gravel at Trenton by a period of considerable physical changes, if not of vast time.

Considering, now, this Trenton gravel, we find it to be limited at the head of tide-water to a level of about forty feet, and diminishing in height relatively to the river both as one ascends and as one descends the channel, until at Yardleyville, a few miles above Trenton, it merges into the terrace which maintains a pretty uniform height of fifteen or twenty feet above the river all the way to the Water-Gap. Above the Water-Gap the gravel terraces rise to a much greater height. At Stroudsburg a second terrace stands seventy-five feet above the first terrace, which is about fifteen feet above Broadhead Creek. But this upper terrace is kame-like in its structure, and hence would be explained in part by the lingering presence of the glacier itself.

The descent of the river-valley from Belvidere, where the

ice-sheet terminated, to Trenton, is two hundred and thirty-two feet, or at the rate of nearly four feet per mile.

Now, the transportation of gravel by a river is dependent both upon the amount of material accessible to the running stream and upon the rapidity of the current. Toward the close of the Glacial period the pebbles accessible to the stream were superabundant, having been deposited in excessive amount by the melting of the glacier in the lower latitudes. The water-worn pebbles at Trenton were probably largely derived from this source. Even a glacial torrent may have more loose material than it can manage, and so may silt up its bed with gravel. Hence it is not necessary to suppose the river at this point to have been of sufficient volume to fill the whole valley with water to the height of the terraces, fifteen or twenty feet. The river may have flowed upon a more elevated gravel bottom in a shallower current than the terrace would seem to imply.

When, now, the current, passing down this declivity of four feet to the mile, reached the level of the sea at Trenton, its transporting power would be greatly diminished, and thus we should have an accumulation of gravel at the head of tide-water, without bringing into the problem the supposition of any very extraordinary increase in the volume of the river. The transporting capacity of a stream of water is estimated to vary as the sixth power of the velocity; i. e., if a current is checked so that it moves at only half its former rate, its transporting capacity is diminished to one sixty-fourth.* It is easy to see that the sudden enlargement of the valley just above Trenton, as well as the occurrence there of tide-water, would diminish the rapidity of the river, and hence cause an extraordinary deposition of gravel when the moraines above were fresh and when ice-fields still lingered in the southern valleys of the Catskills. The process of deposition must have been so rapid that it might well have taken place not long before the withdrawal of the con-

* See Le Conte's "Elements of Geology," pp. 18--20.

tinental glacier to the north of the Catskills. The time required for the river under present conditions to erode the channel it now occupies was of much greater duration. The following is the probable course of events:

1. The Philadelphia brick-clay was deposited during the height of the Glacial epoch, when the Delaware Valley was considerably depressed below its present level. This is McGee's Columbia period.

2. Toward the close of that period, when the land had resumed its present level and the ice had nearly all disappeared south of the Catskills, the still swollen stream brought down the superabundant loose material from the kames and moraines of the glaciated area and deposited it in the valley below. The material was so abundant that doubtless the whole channel was silted up so that the bed of the river was considerably above that it now occupies. At Trenton it flowed over and through an extensive delta of coarse gravel forty feet above its present level; and, above Trenton, over an accumulation of gravel from fifteen to twenty feet above the present high-water mark. This period was marked by the presence of the mastodon and other extinct animals with palæolithic man in the neighborhood of Trenton.*

3. During the Terrace epoch the river worked its way down through the delta gravel at Trenton, and has since eroded its present channel which is about two miles wide at that point. Higher up, where the current is swift, the lateral erosion in recent times has been small.

4. To determine approximately the date of the earliest evidence of man's appearance at Trenton we have as data: (1) The amount of erosion in the gravel at Trenton. (2) The

* It should have been mentioned earlier that Professor Cook found in this gravel, fourteen feet below the surface, the tusk of a mastodon, and that near the same place, at a depth of sixteen feet from the surface, Dr. Abbott took from it a portion of a human under-jaw, also from another place a human tooth, and from still another a "very thick and in several respects singular human cranium." Interesting as these are, however, they are too fragmentary to add materially to our information derived from the implements. See "Annual Geological Report for New Jersey for 1878," p. 24; "Report of Peabody Museum for 1886," p. 408.

general evidence from other sources bearing upon the date of the close of the Glacial epoch in this country, more fully treated of in the preceding chapter.

Since my first visit to Trenton I have studied attentively all the streams situated like the Delaware with reference to the glaciated area between the Atlantic Ocean and the Mississippi River, and can state from personal observation, as heretofore detailed, that a common cause, which can not be anything else than glacial floods operating while the ice remained over the head-waters of these streams, has been at work filling them with gravel-deposits similar to those described along the Delaware. Without exception, those southerly-flowing streams, whose drainage area lies to any considerable extent within the glaciated regions, are lined by extensive terraces of the overwash gravel of the Glacial period.

On obtaining definite information as to these facts, I at once pointed out * the importance of having local observers turn their attention to the discovery of palæoliths at various points in Ohio, where the glacial conditions were similar to those in the valley of the Delaware at Trenton. In my report to the Western Reserve Historical Society (p. 26) I wrote as follows: "The gravel in which they [Dr. Abbott's implements] are found is glacial gravel deposited upon the banks of the Delaware when, during the last stages of the Glacial period, the river was swollen with vast floods of water from the melting ice. Man was on this continent at that period when the climate and ice of Greenland extended to the mouth of New York Harbor. The probability is, that if he was in New Jersey at that time, he was also upon the banks of the Ohio, and the extensive terrace and gravel deposits in the southern part of our State should be closely scanned by archæologists. When observers become familiar with the rude form of these palæolithic implements, they will

* "American Journal of Science," vol. cxxvi, pp. 7–14; "The Glacial Boundary in Ohio, Indiana, and Kentucky"; "Western Reserve Historical Society," 1884, pp. 26, 27; "Ohio Archæological and Historical Quarterly," vol. i, pp. 176, 177.

doubtless find them in abundance. But whether we find them or not in this State [Ohio], if you admit, as I am compelled to do, the genuineness of those found by Dr. Abbott, our investigation into the glacial phenomena of Ohio must have an important archæological significance, for they bear upon the question of the chronology of the Glacial period, and so upon that of man's appearance in New Jersey."

The substance of these remarks had been previously made by me in a meeting of the "Boston Society of Natural History" for March 7, 1883, and reported in "Science," vol. i, pp. 269-271. Commenting upon this report Dr. Abbott sent a communication to "Science," from which the following extracts are very significant and interesting as connected with the discussion :

In "Science" of April 13th, p. 271, Professor Wright remarks that "no palæolithic implements have yet been found [in Ohio], but they may be confidently looked for." It has seemed to me possible, from my own studies of the remains of palæolithic man in the valley of the Delaware River, that traces of his presence may only be found in those river-valleys which lead directly to the Atlantic coast, and that palæolithic man was essentially a coast-ranger, and not a dweller in the interior of the continent. If we associate these early people with the seal and walrus rather than with the reindeer, and consider them essentially hunters of these amphibious mammals rather than of the latter, it is not incredible, I submit, that they did not wander so far inland as Ohio, nor even so far as the eastern slope of the Alleghanies ; and we need not be surprised if palæolithic implements, concerning which there can be no doubt whatever—for recent Indians made and used stone implements that are "palæolithic" in character—are not found in Ohio, nor even in Pennsylvania west of the valley of the Susquehanna River. . . .

On the other hand, if the relationship of palæolithic man and the Eskimo is not problematical, and the latter is of American origin, then I submit that man was preglacial in America, was driven southward by the extension of the ice-sheet, and probably voluntarily retreated with it to more northern re-

gions ; and, if so, then in Ohio true palæolithic implements will surely be found, and evidences of man's preglacial age will ultimately be found in the once-glaciated areas of our continent.*

The expectation of finding evidence of preglacial man in Ohio was met not long after this.

At a meeting of the Boston Society of Natural History † for November 4, 1885, "Mr. Putnam showed an implement chipped from a pebble of black flint, found by Dr. C. L.

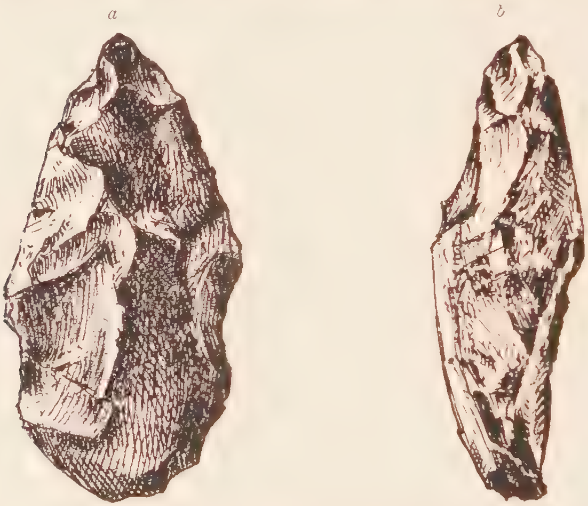

Fig. 166.—Chipped pebble of black chert, found by Dr. C. L. Metz, October, 1885, at Madisonville, Ohio, in gravel eight feet from surface under clay. *a*, face view ; *b*, side view. Note its resemblance to Fig. 126, from Trenton, New Jersey. (No. 40,970.) (Putnam.)

Metz, in gravel, eight feet below the surface, in Madisonville, Ohio. This rude implement is about the same size and shape of one made of the same material, found by Dr. Abbott in the Trenton (N. J.) gravel, and is of special interest as the first one known from the gravels of Ohio." Professor Putnam's announcement, followed by a letter from Dr. Metz, saying that he had since found another implement in the

* "Science," vol. i, p. 359. † "Proceedings," vol. xxiii, p. 242.

gravel at Loveland, led me, on the 11th and 12th of November, 1887, to visit the localities and see their relation to the glacial deposits of the region. The situation is as follows:

FIG. 167.—Map showing glacial boundary, channels, and terraces near Cincinnati.

Madisonville is situated eleven miles northeast of Cincinnati, in a singular depression connecting the Little Miami River with Mill Creek, about five miles back from the Ohio (see Fig. 167). The Little Miami joins the Ohio some miles above Cincinnati, while Mill Creek joins it just below the

city. The general height of the hills in that vicinity above the river is from four hundred to five hundred feet. But the hills just north of Cincinnati are separated from the general elevation farther back by the depression referred to, in which Madisonville is situated.

The depression is from one to two miles wide, and about five miles long, from one stream to the other, and is occupied by a deposit of gravel, sand, and loam, clearly enough belonging to the Glacial-terrace epoch. Recent investigations make it probable that the Ohio formerly flowed north through Mill Creek, and joined the Great Miami near Hamilton. The surface of this is generally level, and is about two hundred feet above the low-water mark in the Ohio. On the east side, on the Little Miami River, at Red Bank, opposite Madisonville, the gravel is coarse, merging into pebbles from one to three or four inches through, interstratified with sand, and underlaid, near the river-level, with fine clay. There is here a thin covering of loess, or fine loam. On going westward this loess-deposit increases in thickness, being at Madisonville, one mile west, about eight feet thick. Farther west it is much deeper, and seems to take the place of the gravel entirely. At several railroad cuttings, compact glacial clay appears underneath all.

Thus, it is evident that this cross-valley, connecting Mill Creek with the Little Miami back of Avondale, Walnut Hills and the observatory, was once much deeper than now, and has been filled in with deposits made when immense glacial floods were pouring down these two streams from the north. The Little Miami was a very important line of glacial drainage, as is shown by the extensive gravel-terraces all along its course, to which the railroads resort for ballast. The coarser material was deposited near the direct line of drainage, where the current was strong, while back from the river toward Madisonville, there was naturally an increase of the fine deposit, or loess, which is practically a still-water formation.

In making an excavation for a cistern, Dr. Metz penetrated the loess, just described, eight feet before reaching

the gravel, and there, just below the surface of the gravel, the implement referred to was found. There is no chance for it to have been covered by any slide, for the plain is extensive and level-topped, and, according to Dr. Metz, there had evidently been no previous disturbance of the gravel.

Subsequently, in the spring of 1887, Dr. Metz found another palæolith in an excavation in a similar deposit in the northeast corner of the county, on the Little Miami across from Loveland. The river makes something of an elbow here, open to the west. This space is occupied by a gravel-terrace about fifty feet above the stream. The terrace is composed in places of very coarse material, much resembling that of Trenton, N. J., where Dr. Abbott has found implements. The excavation is about one quarter of a mile back from the river, near the residence of Judge Johnson. The section shows much coarser material near the surface than at the bottom. The material is largely of the limestones of the region, with perhaps ten per cent of granitic pebbles. The limestone pebbles are partially rounded, but are mostly oblong. Some of them are from one to three feet in length. These abound for the upper twenty feet of the section on the east side toward the river. One granitic bowlder noticed was about two feet in diameter. On the west side of the cut, away from the river, mastodon-bones were found in a deposit of sand underlying the coarser gravel and pebbles. It was here, about thirty feet below the surface, that Dr. Metz found the palæolithic implement referred to.

In October, 1889, Mr. W. C. Mills, president of a local archæological society of some importance at Newcomerstown, on the Tuscarawas River, in Ohio (see map on page 168), found a flint implement of palæolithic type fifteen feet below the surface of the glacial terrace bordering the valley at that place. The facts were noted by Mr. Mills in his memorandum-book at the time, and the implement was placed with others in his collection. But, as he was not familiar with implements of that type, and did not at the time know the significance of these gravel deposits, nothing was said about it until meeting me the following spring, when I was led from his account to suspect

the importance of the discovery. Mr. Mills soon after sent the implement to me for examination, and its value at once became apparent. In company with Judge C. C. Baldwin and two or three other prominent citizens of Cleveland, I immediately visited Newcomerstown. A cut

FIG. 168.—The smaller is the palæolith from Newcomerstown, the larger from Amiens (face view).

of the implement is given in the accompanying pages, made from a photograph one quarter the diameter. Beside it is a palæolith which came into my possession from Dr. Evan's collection in London, with his certification that it is from the valley of the Somme. The two implements as they appear side by side, are in shape and finish the exact

counterparts of each other. The one from Newcomerstown, however, is made from a local flint which occurs in nodules in the "Lower Mercer" limestone, which is situated in the lower part of the coal-measures, and crops out a few miles from there.

FIG. 169. Edge view of the preceding.

The implement has upon it the patina characteristic of the genuine flint implements of great age in the valley of the Somme, and is recognized by Professor Haynes, of Boston, as in itself fullfilling all the requirements looked for in such a discovery. The gravel-pit in which it was found is one which for some years has been resorted to by

the railroads for ballast. Mr. Mills saw the implement as it was projecting from the undisturbed gravel in the fresh exposure, and took it out with his own hands. The surface of the glacial terrace is here thirty-five feet above the prefent high-water mark of the river, and, as already said, the implement was found fifteen feet below the surface. The terrace is one which characterizes the Tuscarawas River everywhere below the glacial boundary, and the illustration upon page 324 might well have been taken from this very spot.

FIG. 170.—Face View of the Implement

FIG. 171—Face View.

FIG. 172—Diagonal View of Sharpened Edge.

In 1892 another important discovery was made in the upper terrace of the Ohio River at Brilliant, Ohio. This was a well fashioned flint implement one inch long which was found in place beneath eight feet of cross bedded sand and gravel where there had been no chance for secondary deposition or a land slip. The surface of the terrace was nearly uniform for two miles in length and a quarter of a mile in width at a height of 80 feet above low water, and fifty feet above the present high water mark. Excavations near by to a depth of 43 feet show continuous cross bedded stratification of sand and gravel with clay in small quantities. Mr. Sam Huston, the County Surveyor, and a well known geological collector of highest

reputation saw the point of the implement projecting from the perpendicular bank while the workmen were at dinner, and extracted it with his own hands. The implement was submitted to the joint meeting of the Geological and Anthropological sections of the American Association for the Advancement of Science at Springfield Mass., in 1895, where Professor F. W. Putnam, Mr. F. H. Cushing and Miss Alice Fletcher and others all recognized it as an indubitable relic of great antiquity.

Its great age was indicated by the patina with which it was covered, and by the fact, instantly recognized by Dr. Cushing, that the form was antique, being intermediate between that of paleoliths and modern Indian implements.

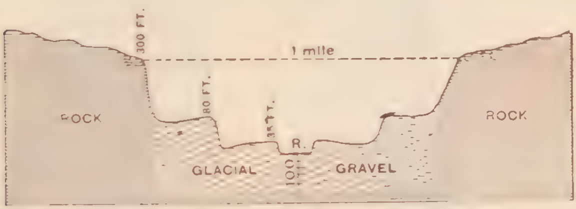

FIG. 173.—Section of the Trough of the Ohio at Brilliant. Location of the implement shown by a *.

For full accounts see "Popular Science Monthly" for December 1895, pp. 157–166.

The cumulative evidence of these facts is increased with the discovery, by Mr. Hilborne T. Cresson, of Philadelphia, in 1886, of implements of similar type in Medora, Ind. Medora is situated in Jackson county, about one hundred miles west of Cincinnati, and is on the border of the glaciated region in that State. The situation is upon the East Fork of White River, near where it enters the triangular unglaciated portion of Southern Indiana as seen in the map of the glacial boundary. The eastern border of this consists of sand-

FIG. 174.—Palæolith of gray flint, found by Mr. H. T. Cresson, May 1886, at Medora, Indiana, in glacial gravel, eleven feet from surface, in bluff on east fork of White River. (Face view.) (No. 46,145.) (Putnam.)

Fig. 175.—Side view of the preceding. (Putnam.)

stone knobs formed by the outcropping of the subcarboniferous strata, which here dip to the west. The unglaciated area is, therefore, considerably higher than that which adjoins it on the east, and is much cut up into gorges along the drainage lines, and must have furnished a favorite retreat, both for man and animals, during the maximum extension of the ice.

Mr. Cresson, having been called into this locality on business, and finding that it was near the glacial boundary as I had recently traced it, was led to turn aside for an hour or two to examine a bank of modified drift. While digging with his hunter's knife under a bowlder of about one hundred pounds weight to see if it showed signs of glaciation, he, to his surprise encountered a well-wrought palæolithic flint implement. Fortunately, a long experience in exploring the gravel-beds in France where palæoliths occur (and, indeed from experience in exploring while a youth a shelter-cave which we will hereafter describe, on the banks of the Delaware) had prepared him fully to appreciate the discovery;

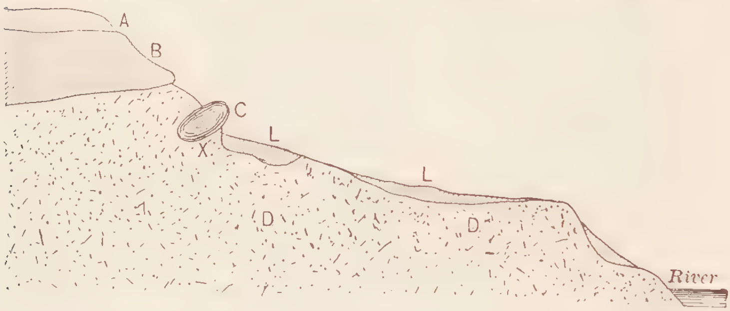

FIG. 176.—Section of glacial gravel at Medora, Indiana, in which Mr. Cresson found the palæolith figured in the text. A, is a deposit of soil three feet in depth; B, modified drift eight feet in depth; D, is probably till; L, L, layers of alluvium; C, the bowlder, under which the implement was found at X.

and he remained a day or two until he had thoroughly investigated the surroundings and made further search for implements. Such search, however, was not rewarded with success, since all that he found later were from the surface, and of a neolithic type. According to Mr. Cresson, this palæo-

lith was found in undisturbed gravel about fifty feet above the flood plain of the river. The gravel was firmly packed, and the implement was with difficulty extricated from it with his hunting-knife. Above it and the bowlder just mentioned were eight feet of gravel and loam, capped by three feet of soil. Mr. Cresson was thoroughly convinced that it would have been impossible for any implement of recent manufacture to have rolled down from the soil above and assume the position it was in with reference to the bowlder. Besides, the implement is of a true palæolithic type, and has the usual marks of age characterizing such implements.*

FIG. 177.—1, *a*, convex surface of a chert implement found at the mouth of Little Elk River, Morrison County, Minnesota, supposed to be a scraper. 1, *b*, profile view of the same.† 2, *a*, convex surface of a chert implement found at Little Falls, Minnesota. 2, *b*, profile view of the same. The figures do not perfectly represent the evidently chipped edges. (Winchell.)

Another locality especially worthy of attention, in which palæoliths have been found, is at Little Falls, Morrison county, Minnesota, the situation of which can readily be seen by reference to the map on page 546. The first discoveries at this point were made as long ago as 1877, and an account of them was given in the "Sixth Annual Geological Report of Minnesota." ‡ These implements were made from chert and quartz, and were recognized by Professor N. H.

* See Mr. Cresson's report on the subject, in the "Proceedings of the Boston Society of Natural History," vol. xxiv, p. 150 *et seq.*

† This specimen is regarded a finished implement by Putnam. ‡ Pp. 53–58.

Winchell as belonging to the age of the glacial deposits which here line the trough of the Mississippi. A little later, Miss Franc E. Babbitt examined the locality more carefully, and found a large number of additional implements. Her discoveries were first reported in a paper read before the Minnesota Historical Society in February, 1880. A fuller account was presented at the meeting of the American Association for the Advancement of Science at Minneapolis in August, 1883. At that time also the subject was thoroughly canvassed by the numerous geologists present, and a paper was read upon the subject by Mr. Warren Upham, to whose work upon the surface geology of the Northwest we have so often had occasion to refer. To get the whole subject before our readers we can do no better than to append the principal portion of an elaborate paper read by Mr. Upham before the Boston Society of Natural History, on December 31, 1887, which will be the more readily understood by reason of the previous chapters of the present volume detailing the general results of Mr. Upham's work in that region:

The recession of the ice-sheet of the last Glacial epoch in Minnesota seems to be clearly marked by as many as ten stages of halt or readvance, in which distinct marginal moraines were accumulated, besides the moraine on the limits of its farthest extent. Six summers of geologic field-work in that State have been spent by the writer chiefly in the examination of its glacial and modified drift, of these moraines, and of the beaches and deltas of the glacial Lake Agassiz, which was formed in the valley of the Red River of the North and of Lake Winnipeg by the barrier of the departing ice-sheet. In their bearings upon this subject, my observation and study of that region convince me that the rude implements and fragments of quartz discovered at Little Falls were overspread by the glacial flood-plain of the Mississippi River, while most of the northern half of Minnesota was still covered by the ice, contemporaneously with its formation of the massive moraines of the Leaf Hills and with

the expansion of Lake Agassiz on their west side, respectively sixty and eighty-five miles west of Little Falls. This was during the highest stage of Lake Agassiz, and previous to its extension beyond the north line of Minnesota and Dakota. More than twenty lower beaches of this glacial lake have been traced, belonging to later stages in the recession of the ice-sheet, before it was melted so far as to reduce Lake Agassiz to its present representative, Lake Winnipeg. Estimated by comparison with the series of moraines and beaches formed during the glacial recession, the date of the gravel plain at Little Falls appears to be about midway between the time of maximum extent of the last ice-sheet and the time of its melting on the district across which the Nelson River flows to Hudson Bay.

The town of Little Falls is on the east bank of the Mississippi River, in Morrison county, near the geographic center of Minnesota. It is about a hundred miles northwest from St. Paul and Minneapolis, and nearly an equal distance southeast from Itasca Lake. The elevation of Itasca Lake is about 1,450 feet above the sea; of the Mississippi, at the head of the rapids or Little Falls, from which the town derives its name, 1,090 feet; and at the head of St. Anthony's Falls in Minneapolis, 796 feet. Following the general course of the river, without regarding its minor bends, its descent from Lake Itasca by Little Falls to Minneapolis averages about two feet per mile, and is approximately uniform along the entire distance. Considered in a broad view, this central part of the State may be described as a low plateau, elevated a few hundred feet above Lake Superior on the east and the Red River Valley on the west. In most portions it is only slightly undulating or rolling, but these smooth tracts alternate with belts of knolly and hilly drift, the recessional moraines of the ice-sheet, which commonly rise fifty to one hundred feet, and in the Leaf Hills one hundred to three hundred and fifty feet above the adjoining country. The bed-rocks are nearly everywhere concealed by the drift-deposits, into which the streams have not eroded deep valleys, their work of this kind being mostly limited to the removal of part of their glacial flood-plains. The upper portions of the Mississippi and of its

chief tributaries, and all the smaller streams throughout this region, flow in many places through lakes which they have not yet filled with silt nor drained by cutting down their outlets. At Little Falls the glacial flood-plain of the Mississippi is about three miles wide, reaching two miles east, and one mile west from the river. Its elevation is twenty-five to thirty feet above the river at the head of the rapids, which have a descent of seven feet. The Mississippi here flows over an outcrop of Huronian slate, and the same formation is also exposed by the Little Elk River near its mouth, on the west side of the Mississippi three miles north of Little Falls. Veins of white quartz occur in the slate at both these localities, and were doubtless the source of that used by man here in the Glacial period for the manufacture of his quartz implements.

The locality and section of the modified drift, where these worked fragments of quartz were found by Miss Babbitt, and the account of their discovery, are best told in her own words from her paper read before the Anthropological Section of the American Association for the Advancement of Science at its Minneapolis meeting in 1883. I quote as follows:

"Rudely worked quartzes had previously been discovered here by the State Geologist of Minnesota, Professor N. H. Winchell, by whom they had been described and figured in the State Geological Report for 1877. . . . The find reported by Professor Winchell consists of chipped objects of a class generally ascribed to what is called the rude stone age. Of these many appear to be mere refuse, while others are regarded as finished and unfinished implements. The Winchell specimens have been assigned, upon geological ground, to a prehistoric era antedating that of the mound-building races, and reaching back to a time when the drift material of the terrace-plain was just receiving its final superficial deposit. It is found that, at intervals, the surface soil of the terrace contains these quartzes to a depth of not unfrequently three or four feet.

"The lowest and newest formation at this place is the present flood-plain of the river. It is still in process of deposition, being yet subject to partial overflows at periods of

exceptionally high water. In that portion of the town of Little Falls situated east of the Mississippi, this bottom-land is limited on the east by a high, ancient river-terrace, which has here an average elevation of about twenty-five feet above the river. . . . This older terrace, like the present flood-plain, has been spread out by the immediate action of water. . . .

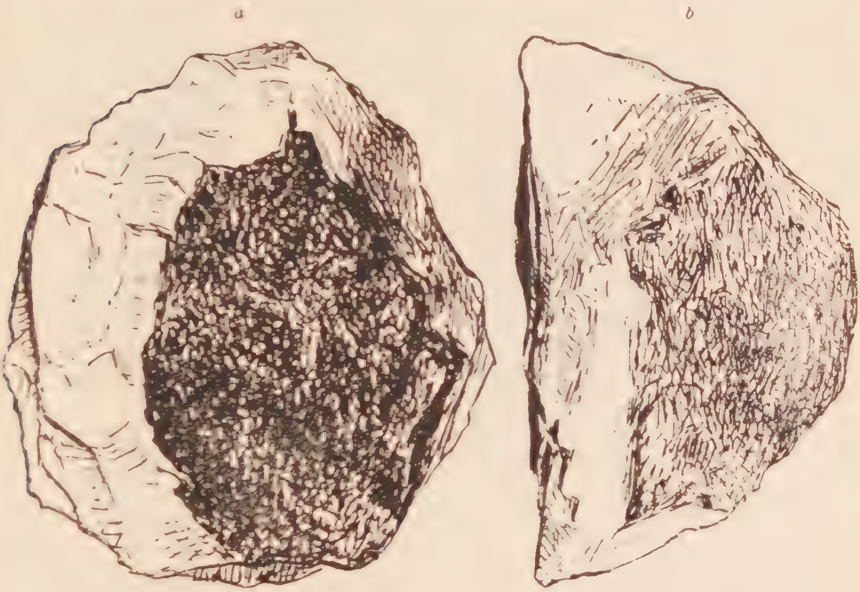

FIG. 178.—Quartz implement, found by Miss F. E. Babbitt, 1878, at Little Falls, Minnesota, in modified drift, fifteen feet below surface. *a*, face view; *b*, profile view. The black represented on the cut is the matrix of the quartz vein. (No. 31.323.) (Putnam.)

While occupied in examining the river bank at Little Falls in quest of wrought quartzes, one day during the season of 1879, I had occasion to ascend a slope lying between the new flood-plain and the older terrace, by a path leading through a sort of gap or notch in the latter (three hundred and ten rods, very nearly, or almost one mile north of the east-west road by Vasaly's Hotel; ten rods west of the road to Belle Prairie; and thirty-eight rods from the river). . . . It seemed that at some past period a cut had been effected here by drainage, and that the wash-out thus formed had afterward been deepened by being

used, now and then, as a wagon-track. In this notch I discovered the soil to be thickly strewed with pieces of sharp, opaque quartz. These were commonly of a white color, and ranged in size from minute fragments to bits as large as a man's hand, and in some instances even larger. There were many hundreds of these chips visible, scattered over an area

FIG. 179.—Quartz implement, found by Miss F. E. Babbitt, 1878, at Little Falls, Minnesota, in modified drift, fifteen feet below surface. *a*, face view ; *b*, side view. (No. 31,316.) (Putnam.)

the width of the wagon road, and ten or fifteen yards in length. They were conspicuously unwaterworn, and likewise mostly unweathered, though occasionally a bit was picked up having some one of its surfaces weathered, while fractured or wrought faces appearing upon other parts of it, looked as fresh as if the work of yesterday. On the other hand, the mass of stone rubbish upon and among which the quartzes were strewed is much water-worn, many of the pieces being well rounded, while none of them are wholly angular.

"By continued observations at this locality, I found that many of these quartz chips were brought to light at every succeeding freshet of the season, being washed out of the sand by

descending drainage. Their immense and continually increasing numbers seemed to warrant the belief that they had resulted from systematic operations of some sort, once conducted, for unknown purposes, upon this particular spot. A portion of the studied specimens subsequently yielded evidence of having received shape from human hands, and therefore it was assumed provisionally that the site of exposure represented a prehistoric workshop.

"Prolonged investigation ensued; and investigation established the hitherto unsuspected fact that no quartz chips nor fragments were inclosed in the upper part of the gravel and sand terrace at the notch, nor within a considerable distance at either hand, though they were sought with careful scrutiny. . . . Ultimately it was ascertained that the notch quartzes had dropped to the level at which they were seen from a thin layer of them once lying from ten inches to two feet above it, and subsequently broken up through the wearing away of the sand underneath by drainage. This layer or stratum was still intact on the north and south and partially so on the east, in which direction it had, however, at certain points, suffered some displacement by wagoning. It extended in a nearly horizontal plane into the terrace, in the sloping edge of which the notch, opening into its west bank and truncated at its edge, is cut. . . . The quartz-bearing layer averaged a few inches only in thickness, varying a little as the included pieces happened to be of smaller or larger size. The contents were commonly closely compacted, so much so that one might sometimes extract hundreds of fragments, many of them very small ones, of course, from an area of considerably less than a square yard.

"The quartz bed, so far as examined, rested upon a few inches of sandy soil, which passed downward into a coarse water-worn gravel, immediately overlying till. Above the quartz chips, stratified gravel and sand extended up to the surface of the terrace. The pebbles of the gravel lying directly on the quartz-bearing stratum were small and well rounded, and were noticeably less angular than those of the gravel below. The stratum of quartz chips lay at a level some twelve or fifteen feet lower than the plane of the terrace-top.

"These observations show that the quartz chips were spread

originally upon an ancient surface that has been since covered deeply by the modified drift which forms the terrace. It will be remembered that the quartz chips and implements discovered by Professor Winchell in this vicinity are contained in the upper stratum of the terrace-plain; but the notch quartzes do not occur at the terrace-top, and can not have been derived from it, but are confined strictly to a single stratum of the lower gravels closely overlying the till. Hence the two sets of objects can not be synchronous, though they may have been produced by the same race at different stages of its existence. The notch quartzes must, of course, be older than those described by Professor Winchell, by at least the lapse of time required for the deposition of the twelve or fifteen feet of modified drift forming the upper part of the terrace-plain, above the quartz-bearing stratum."

This description by Miss Babbitt shows that these implements and fragments of chipped quartz occurred in a well-defined thin layer in the modified drift forming the glacial flood-plain of the Mississippi River, as shown in the section which I have drawn (see the following figure). I have examined the

Fig. 180.—Section across the Mississippi Valley at Little Falls, Minnesota, showing the stratum in which chipped quartz fragments were found by Miss F. E. Babbitt, as described in the text. (Upham.)

terraces and plains of this valley drift from St. Paul and Minneapolis to Brainerd, some twenty-five miles north of Little Falls, and find them similar in material and origin with the modified drift terraces in the valleys of the Merrimack, Connecticut, and other rivers in New England. These water-courses extending southward from the region that was covered by the ice-sheet became the avenues of drainage from it during its retreat. A part of the drift which had been contained in the lower portion of the ice was then washed away by the streams formed on the ice in its rapid melting and was deposited as modified drift, forming layers of gravel, sand, and fine silt, in the valleys along which the floods supplied by this melting descended toward the ocean. Along the Mississippi

the flood-plain of modified drift at Brainerd has a height of about 60 feet above the river; at Little Falls, as before noted, its height is 25 to 30 feet; at St. Cloud, 60 feet; at Clearwater and Monticello, 70 to 80 feet; at Dayton, 45 feet; and at Minneapolis, 25 to 30 feet above the river at the head of St. Anthony's Falls.

The modified drift at Little Falls lies on the till or direct deposit of the ice-sheet, and forms a surface over which the ice never readvanced. It lies far within the area that was ice-covered in the second and latest principal epoch of glaciation, and by reviewing the steps in the recession of the ice of that epoch we shall be able to ascertain approximately what were the outlines of its receding margin when the gravel and sand plain of Little Falls was deposited, inclosing these evidences of man's presence. The ice-sheet, supplying both this modified drift and the floods by which it was brought, still covered much of the upper part of the Mississippi basin, which only reaches about a hundred miles north of Little Falls; and the courses of massive morainic belts show the continuation of the glacial boundary northwestward across Dakota and with less clearness eastward across the Laurentian lakes.

When the latest North American ice-sheet attained its greatest area, its southern portion from Lake Erie to Dakota consisted of vast lobes, one of which reached from central and western Minnesota south to central Iowa. This lobe in its maximum extent ended near Des Moines, and its margin was marked by the Altamont moraine, the first and outermost in the series of eleven distinct marginal moraines of this epoch which are recognizable in Minnesota. When the second or Gary moraine was formed, it terminated on the south at Mineral Ridge in Boone county, Iowa. At the time of the third or Antelope moraine, it had farther retreated to Forest City and Pilot Mound in Hancock county, Iowa. The fourth or Kiester moraine was formed when the southern extremity of the ice-lobe had retreated across the south line of Minnesota and halted a few miles from it in Freeborn and Faribault counties. The fifth or Elysian moraine, crossing southern Le Sueur county, Minnesota, marks the next halting-place of the ice. At the time of formation of the fifth moraine, the south

end of the ice-lobe had been melted back a hundred and eighty miles from its farthest extent, and its southwest side, which at first rested on the crest of the Coteau des Prairies, had retired thirty to fifty miles to the east side of Big Stone Lake and the east part of Yellow Medicine county. During its next stage of retreat this ice-lobe was melted away from the whole of Le Sueur county, and its southeast extremity was withdrawn to Waconia, in Carver county, where it again halted forming its

FIG. 181.—Map showing the stages of recession of the ice in Minnesota as described in the text. (Upham.)

sixth or Waconia moraine. The seventh or Dovre moraine marks a pause in its recession when its southeast end rested on

Kandiyohi county. Probably nearly all of the southern half of Minnesota was at this time divested of its ice-mantle, while nearly all of the northern half was still ice-covered, the glacial boundary across the State passing in an approximately east to west course not far from Little Falls.

By its next recessions the ice-border was withdrawn to the eighth or Fergus Falls moraine, and the ninth or Leaf Hills moraine. These are merged together in the prominent accumulations of the Leaf Hills, which reach in a semicircle from Fergus Falls to the southeast, east, and northeast, a distance of fifty miles, marking the southern limits of this ice-lobe when it terminated nearly due west of Little Falls and half way between the south and north borders of Minnesota. Conspicuous morainic hills a few miles east of Little Falls, and others in the north part of Morrison county and along its west side, seem to be correlated with the Fergus Falls moraine. Much of the modified drift of the Mississippi Valley at Little Falls was probably deposited when the ice-sheet terminated at these hills five to fifteen miles distant on the east, north, and west. Eastward from Morrison county, this moraine continues northeast to the north side of Mille Lacs, thence probably through the south edge of Aitkin county and the north part of Pine county, and onward northeasterly to the west end of Lake Superior. The Leaf Hills moraine extends from the northeast part of the Leaf Hills, near the Leaf Lakes, east across northern Todd county and northwestern Morrison county and then north-northeast by Gull, Pelican, White Fish, and Crooked Lakes. Next it probably takes an eastward course, crossing the Mississippi several miles north of Sandy Lake and the St. Louis River near the mouth of the Cloquet, and thence an east-northeast course passing not far south of the Cloquet River and reaching the north shore of Lake Superior about half-way between Duluth and Pigeon Point. The upper portion of the modified drift at Little Falls, probably including the stratum of chipped fragments of quartz, is referable to the time of the recession of the ice-sheet north from the Fergus Falls moraine to the Leaf Hills moraine. At the west end of the Leaf Hills and thence through a distance of fifty miles northward, this stage of recession carried the ice-border

back only five to ten miles; and in the main Leaf Hills, as before noted, the two moraines are united. Across the Mississippi basin the glacial recession between them uncovered an area mainly twenty to forty miles wide. The portion of the ice-sheet nearest to Little Falls at the time of the Leaf Hills moraine was in the vicinity of Fish-Trap Lake and Lake Alexander, in northwestern Morrison county, only twenty miles distant. There, as in the Leaf Hills, this moraine and that of Fergus Falls come together. Ascending the Mississippi, a distance of eighty miles intervened between Little Falls and the ice-border at the time of the Leaf Hills moraine, which extends approximately parallel with the river and ten to twenty miles from it on its northwest side in passing north-northeastward from Morrison county.

During the formation of the tenth or Itasca moraine, and of the eleventh or Mesabi moraine, crossing the lake region at the head of the Mississippi, the gravel and sand of the modified drift were probably wholly deposited north of Little Falls. Later moraines, formed at times of halt or readvance, interrupting the recession of the ice-sheet between northern Minnesota and Hudson Bay, have not been determined, but I believe that they exist and await discovery when the glacial drift of that wooded and very scantily inhabited region shall be fully explored. The many beaches of Lake Agassiz, all showing an ascent northward when compared with the level of the present time, but with this ascent gradually decreased during the successive stages of the lake, probably find their explanation in the manner of retreat of the ice in Canada, interrupted there, as farther south, by pauses and the formation of moraines.

Contemporaneously with the deposition of the glacial flood-plain at Little Falls and the accumulation of the Leaf Hills, the ice-front forming the north shore of Lake Agassiz crossed the Red River Valley between Fargo and Grand Forks, and extending northwesterly across northern Dakota, as shown by its moraines remarkably developed along the south side of Devil's Lake and onward to Turtle Mountain. Toward the east, the ice-sheet at this time had receded from the southwest part of Lake Superior, which was held about five hundred feet higher than now and overflowed to the St. Croix and

Mississippi Rivers by the way of the Bois Brulé River and Upper St. Croix Lake. It seems nearly certain also that the ice-border continued across Green Bay and the north part of Lake Michigan; and farther east I think that it probably crossed southwestern Ontario and the central or northern portions of New York, Vermont, New Hampshire, and Maine. The Laurentian lakes were dammed by the retreating glacial barrier and overflowed at the lowest points on their southern watershed. The time when the Little Falls stone implements and fragments from their manufacture were covered by the modified drift seems therefore somewhat later than that of the implements found in southern Ohio and in New Jersey; for, if this was the course of the ice-boundary east from the Leaf Hills of Minnesota, it had already receded beyond the region where the glacial floods could be discharged by the Little Miami and Delaware Rivers.

If the question be asked, How many thousand years ago was this? a reply is furnished by the computation of Professor N. H. Winchell, that approximately eight thousand years have elapsed during the erosion of the post-glacial gorge of the Mississippi from Fort Snelling to the Falls of St. Anthony; of Dr. Andrews, that the erosion of the shores of Lake Michigan, and the resulting accumulation of dune-sand drifted to the southern end of that lake, can not have occupied more than seventy-five hundred years; of Professor Wright, that streams tributary to Lake Erie have taken a similar length of time to cut their valleys and the gorges below their waterfalls; and of Mr. Gilbert, that the gorge below Niagara Falls has required only seven thousand years or less. These measures of time carry us back to the date of the Little Falls quartz-workers, when the ice-sheet of the last Glacial epoch was melting away from the basins of the upper Mississippi and of the Laurentian lakes.

Plants and animals doubtless followed close upon the retiring ice-border, and men living in the region southward would make journeys of exploration to that limit, but probably they would not take up their abode for all the year so near to the ice as Little Falls at the time of the Fergus Falls and Leaf Hills moraines. It may be that the chief cause leading men

to occupy this locality, so soon after it was uncovered from the ice, was their discovery of the quartz-veins in the slate there and on the Little Elk River, affording suitable material for making sharp-edged stone implements of the best quality. Quartz-veins are absent or very rare and unsuited for this use in all the rock-outcrops of the south half of Minnesota that had become uncovered from the ice, as well as of the whole Mississippi basin southward, and this was the first spot accessible whence quartz for implement-making could be obtained. While the deposition of the valley-drift at Little Falls was still going forward, men resorted there, and left, as the remnants of their manufacture of stone implements, multitudes of quartz fragments. By the continued deposition of the modified drift, lifting the river upon the surface of its glacial flood-plain, these quartz-chips were deeply buried in that formation. The date of this valley-drift must be that of the retreat of the ice of the last Glacial epoch, from whose melting were supplied both this sediment and the floods by which it was brought. The glacial flood-plain, beneath whose surface the quartz fragments occur, was deposited in the same manner as additions are now made to the surface of the bottom-land ; and the flooded condition of the river, by which this was done, was doubtless maintained through all the warm portion of the year, while the ice-sheet was being melted away upon the region of its head-waters. But in spring, autumn, and winter, or, in exceptional years, through much of the summer, it seems probable that the river was confined to a channel, being of insufficient volume to cover its flood-plain. At such time this plain was the site of human habitations and industry. After the complete disappearance of the ice from the basin of the upper Mississippi, the supply of both water and sediment was so diminished that the river, from that time till now, has been occupied more in erosion than in deposition, and has cut its channel far below the level at which it then flowed, excavating and carrying to the Gulf of Mexico a great part of its glacial flood-plain, the remnants of which are seen as high terraces or plains upon each side of the river.

The question concerning the manner in which human remains have become incorporated in the glacial gravels is

Fig. [illegible]—Accumulating delta plain in front of the Malaspina Glacier. The emerging sub-glacial stream has been diverted into an adjoining forested area and is killing the trees by its accumulations of gravel during flood times. (Photo by Russell.)

of considerable importance as well as interest. Many have seemed to assume that they could come into position only by being dropped into the water from a boat. The accompanying illustration, however, from a photograph of Professor Russell taken in front of the Malaspina Glacier, Alaska, shows what was doubtless the real method. A glacial delta is here seen in process of formation. In the summer time, when the drainage channels were overcharged both with water and *débris* they would build up a delta terrace near their mouth. During a considerable portion of the year, however, these deposits would be exposed surfaces over which man could wander and hunt at his leisure. In the illustration such a stream has been diverted into a forest and is fast burying the trees, as is seen to have been the case in front of the Muir Glacier (see frontis plate). At Trenton, New Jersey, this exposed delta terrace would have been doubly attractive to man from the fact that it contained many pebbles of argillite from which he was accustomed to manufacture his implements.

CHAPTER XXII.

MAN AND THE GLACIAL PERIOD (*continued*).

THE preceding instances all belong, without question, to the later stages of the Ice age in America. Those geologists who speak of two glacial periods would classify the gravels at Trenton, N. J., Madisonville and Loveland, O., Medora, Ind., and Little Falls Minn., as belonging to the later stages of the second Glacial epoch—the deposits at Little Falls being, as Mr. Upham has already stated, somewhat subsequent to any of the others. We come now to a still more startling discovery, made by Mr. Cresson, near his summer residence, on the Delaware River, at Claymont, Del. For a general idea of the situation the reader is referred to the map of New Jersey in the general chapter upon the glaciated area.* The discovery was made while an extensive excavation was in progress connected with the building of the Baltimore and Ohio Railway. It was my privilege, in November 1888, to examine the locality in company with Mr. Cresson, and I here give the results of the observations:

The point is located about one mile and a half west of the river bank, and about one hundred and fifty feet above tide-water. The ascent from the river at Claymont is by three or four well-marked benches. These probably are not terraces, in the strict sense of the word, but shelves marking different periods of erosion, when the land stood at these several levels, but now thinly covered with old river deposits. The cut where the discovery was made is well shown in our

* See p. 141.

FIG. 183.—General view of section of Baltimore and Ohio cut, near Claymont, Delaware, where Mr. Cresson found palæ[illegible] in the text. (From photograph by Cresson.)

accompanying illustration, reproduced from a photograph. The lower part of this cut consists of decomposed schist rocks in place and of deposits which are preglacial. These extend in the illustration to the top of the light band running through the picture. The portion above this light band belongs to what was described in the preceding chapter as pertaining to the formation denominated by Professor Lewis the Philadelphia red gravel and brick-clay, being identical with that at Philadelphia both in its composition and in its stratigraphical relations, and extending continuously down the river from that city (nineteen miles). By Mr. McGee this would be denominated the Columbia formation, since he correlates the deposits in the Delaware Valley with those in the District of Columbia in the valley of the Potomac. The age of this deposit we have already discussed,* and we need here only repeat that it is without doubt a glacial formation of a much earlier period than that farther up the valley at Trenton, N. J., where Dr. Abbott made his important discoveries. While that at Trenton belongs to the later stages of the Ice age, this at Claymont is to be connected with the ice when at its maximum extension, and when the level of the region was depressed one hundred feet or more. In a preceding chapter I have given my reasons for questioning the theory of Mr. McGee, who would connect this deposit with a glacial age previous to, and entirely distinct from, that which was concerned with the deposits at Trenton, and which he would make from three to ten times as remote. But, whichever view upon this point prevails, whether that of two distinct glacial epochs, or of one prolonged epoch with various halts in the retreat of the ice, the Philadelphia red gravel and brick-clay must be regarded on the least calculation as some thousands of years older than the deposits at Trenton, N. J., Loveland and Madisonville, O., Medora, Ind., and Little Falls, Minn.

The circumstances of the discovery are thus reported by Mr. Cresson:

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* See pp. 613, 635 *et seq.*

FIG. 181.—Nearer view of the same, with the finger pointing to the precise place in the bank where the implement was found. (From photograph by Cresson.)

Toward midday of July 13, 1887, while lying upon the edge of the railroad cut, sketching the bowlder line, my eye chanced to notice a piece of steel-gray substance strongly relieved in the sunlight against the red-colored gravel just above where it joined the lower grayish-red portion. It seemed to me like argillite, and, being firmly imbedded in the gravel, was decidedly interesting. Descending the steep bank as rapidly as possible, the specimen was secured . . . Upon examining my specimen, I found that it was unquestionably a chipped implement. There is no doubt about its being firmly imbedded in the gravel, for the delay I made in extricating it with my pocket-knife nearly caused me the unpleasant position of being covered by several tons of gravel. . . . Having duly reported my find to Professor Putnam, I began at his request a thorough examination of the locality, and on May 25, 1888, the year following, discovered another implement, four feet below the surface, at a place about one eighth of a mile from the first discovery. . . . The geological formation at which the implement was found seems to be a reddish gravel mixed with schist.

The implements thus discovered by Mr. Cresson in this early deposit of the Glacial period must be connected with others near by, found by him several years before in a shelter cave, since destroyed by the railroad excavation. This was situated near the small building that appears at the right of our picture.* Interested as a youth in the reports of cave explorations in Europe, he carefully excavated this rock shelter in 1866, making notes of and preserving everything he found. As recorded at the time, the lower part of this cave was filled to a depth of about six feet with a deposit apparently identical with the Philadelphia red gravel and brick clay. This contained only palaeolithic implements of argillite similar to those (figured on the following page) from the railroad cut near by. Argillite implements, mingled with others of jasper, quartzite, and bone, with fragments of pot-

* See Fig. 183, p. 670; also "Proceedings of the Boston Society of Natural History," vol. xxiv, p. 145.

tery and human bones and charcoal, were found nearer the surface. The total depth of the deposit was about fifteen feet.

FIG. 185.—Argillite implement, found by H. T. Cresson, 1887, in Baltimore and Ohio Railroad cut, one mile from Claymont, Delaware, in Columbia gravel, eight to nine feet below the overlying clay bed. *a*, face view; *b*, side view. (No. 45,726.) (Putnam.)

The progress of the race from the Palæolithic to the Neolithic age here suggested corresponds in part to that indicated by Dr. Abbott's discoveries at Trenton, where the transition from the palæolithic type of implement to the more modern types, though sudden at the top of the gravel itself, is gradual from the top of the gravel to the surface of the soil. For, according to him,* argillite implements occur in greatest

* "Proceedings of the American Association for the Advancement of Science," vol. xxxvii.

abundance at the base of the deposit of "black soil" which overlies the gravel to an average depth of about one foot. "The flint implements known as Indian relics belong to this superficial or black soil," and they are found abundantly on the surface, more sparingly near the surface, and "more sparingly still the deeper we go," until, on reaching the gravel proper, they disappear entirely.

In this connection it is interesting to note that at the mouth of Naaman's Creek, the nearest point on the river from the shelter-cave just described, Mr. Cresson has also discovered remains of prehistoric wooden structures below the level of low tide. These consist of the ends of rude piles which had evidently been fashioned by stone implements, but for what purpose intended it is not evident. In dredging here, he found numerous rude argillite implements of the palæolithic type, which, in the vicinity of two of the structures, were mingled with those of a modern type.

Thus the valley of the Delaware would seem to contain a record of the passage of the race on the Atlantic coast from the Palæolithic to the Neolithic age. Here, about as far below the ice-front at that time as the shore of Greenland now is, the hardy hunters who had been driven before the advancing cold of the great Ice age found ample space for their pursuits, and excellent shelter in the dense forests which everywhere bordered the southern front of the great snow-fields. The proximity of the ocean furnished, doubtless, a supply of fish, while numerous animals, long since extinct in this region, were for a time fellow-fugitives with man from the advancing northern foe. Among these companions of man we may pretty certainly include the mastodon (one of whose tusks, as already remarked, was found by Professor Cook in the Trenton gravel itself), the walrus, the Greenland reindeer, the caribou, the bison, the moose, and the musk-ox, for the remains of all these animals are found either in the superficial gravel deposits of southern New Jersey, or in the adjoining region of country to the south and west. The picture of human life during that period in the valley of the

Delaware is substantially the same as that presented by the archæologists of Europe for southern England and northern France in the declining years of the Glacial period.

Fig. 18[illegible].—Panoramic view showing Mr. Concannon's house and the relation of the bluff to the present flood plain of the Missouri River. (Courtesy of Records of the Past

CHAPTER XXIII.

MAN IN THE MISSOURI VALLEY.

Professor N. H. Winchell* has given a complete list of human remains supposed to have been found in the loess of the Missouri Valley, which belongs to the deposits of the Iowan stage of the glacial recession. But so much uncertainty surrounds several instances of these that it will be sufficient to mention only three of the best authenticated and most significant cases, viz., those found at Lansing, Kansas, and at Florence near Omaha, Nebraska, and at St. Joseph, Missouri.

The important discovery at Lansing, Kansas, was made in February 1902, by Mr. Martin Concannon while excavating a tunnel underneath his residence, and was brought to the notice of the public by Mr. M. C. Long of Kansas City, Missouri. The skeleton was found seventy-two feet from the mouth of the tunnel. The excavation was carefully and repeatedly examined by various expert geologists, including Professors T. C. Chamberlin, R. D. Salisbury, S. W. Williston, E. Haworth, N. H. Winchell, Warren Upham and W. H. Holmes. I can also speak from careful personal inspection of the whole locality. Subsequently also Mr. Gerard Fowke and Mr. Long were engaged by Mr. Holmes to dig a cross section striking the tunnel near the place where the skeleton was found. The unanimous testimony was that the remains occurred as reported in undisturbed loess. In fact several other less important human relics were found by Mr. Fowke in his excavations.

* "Records of the Past," vol. vi (May 1907), pp. 148–157.

The only questions as to the glacial age of the relic is whether this remnant of loess belongs to the original deposit connected with the Iowan stage of glacial recession, or whether it may not have been re-deposited at some later stage of river erosion. Professor Chamberlin maintained that it was a secondary deposit, and that its antiquity "is measured by

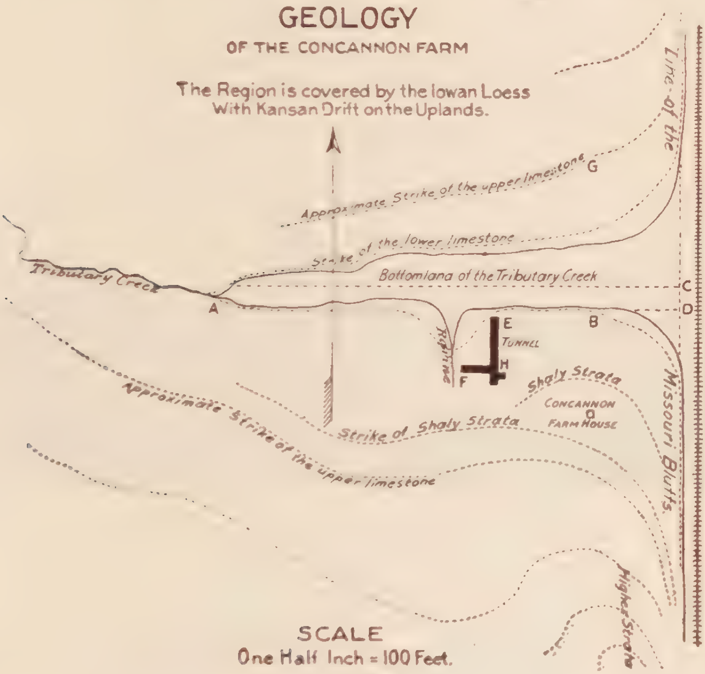

FIG. 187.

the time occupied by the Missouri River in lowering its bottom, two miles more or less in width, somewhere from fifteen to twenty-five feet, a very respectable antiquity, but much short of the close of the glacial invasion."* But after three visits to the locality, Professor Winchell seems to show conclusively that the loess belongs to the original undisturbed

* "Journal of Geology," October–November, 1902.

deposit of Iowan age. My own personal investigations on the ground amply sustain this view as will appear from study of the accompanying illustrations.

The remnant of loess is protected on a rocky promontory left between the main valley of the Missouri and a small stream whose channel dates from preglacial times. The stratum near the bottom of the tunnel in which the skeleton was found is between eleven and twelve feet above the extreme present highwater mark of the river, while the loess overlying the skeleton is twenty feet thick; and loess underlies the house

FIG. 188—View showing entrance to tunnel in which the Lansing Skeleton was found (Courtesy of Records of the Past.)

still several feet higher, and mantles the narrow slope well up to the 200 foot level constituting the loess plain which furnishes the location for the city of Leavenworth, a short distance away. West of the tunnel, also, the loess slopes rapidly upwards to the same level.

The most conclusive witness to the original and undisturbed character of the deposit in which the tunnel was excavated will be seen from a study of the accompanying map. The bottom of the tunnel is on a rock exposure of limestone whose outcrop extends from B to the side ravine, where, after a short interruption, it appears on the other side westward to

A, where the main tributary creek descends from the apex of a rocky gorge into what is evidently a preglacial portion extending 500 feet from A to C. There is no rock visible in

[illegible] Lansing Skeleton. (Courtesy of Records of the Past.)

the valley from A to C, and the water which in dry weather comes into its head continually disappears in the gravel underneath, whose surface at the entrance of the tunnel is

Fig. 190—Side view of skull and femur bones of Lansing Skeleton. (Courtesy of Records of the Past.)

twenty feet below the rock exposure, while a well a little farther east was sunk to a depth of twenty-four feet without striking rock, and the railroad immediately east of the mouth of the

buried gorge is supported by piles driven thirty feet into the alluvium. Above A this ravine lies wholly in the enveloping loess.

From this it is evident that the rock erosion in the lower part of the tributary entering at A is neither post-glacial nor interglacial, but is a remnant of preglacial erosion when the whole region was so much elevated that the river had lowered its bed a considerable depth below that now occupied by it. At Omaha the rock bottom of the river is known to be eighty feet below its present bottom. Since the advent of the continental ice-sheet the preglacial gorge has been aggraded to a considerable extent, and meanwhile, during the Iowan stage of the glacial period the loess bluffs of the Missouri Valley, here so pronounced, were deposited on the ever rising flood-plain of the torrents which for many centuries poured out from the melting ice during the closing stages of the epoch. The Lansing skeleton antedates the deposition of the entire loess formation.

Positive evidence of the aqueous character of the loess overlying the skeleton, was noted by Mr. Upham; namely, a "distinct darker layer of loess mostly about two inches thick but in part merely a threadlike line, traceable continuously through all the seventy-two feet of the west wall of the tunnel, running about three or four feet above the limestone floor, and one foot or a little more above the base of the loess." This extended in a straight plane descending from south to north about one inch to ten feet. Other lines of nearly horizontal stratification were also observed, thus clearly showing that it is an aqueous deposit of the same character with that of the loess of the whole valley.

The most plausible suggestion for the later deposition has been made by Professor J. E. Todd,* who thinks it possible that the loess on which the Concannon house stands may be

* "Recent Alluvial Changes in Southwestern Iowa," "Proceedings of Iowa Academy of Science," 1907, pp. 257–266.

the remnant of a cone of dejection brought down from the adjoining loess terrace when the Missouri River was flowing on the opposite side of the trough, two miles distant. Some remarkable facts are given by him of the rapid growth of such cones in the Missouri Valley opposite Nebraska City, since the occupation of the country by whites. But the fact, just stated concerning the slight northward dip of the stratification noted by Dr. Upham, and the extent to which the remnant of the deposit runs up the ridge back of the house towards the main terrace would seem to render Professor Todd's theory incredible.

As to the skeleton itself, it so much resembles that of some modern American Indians, that the Americanists who examined it at the International Meeting in New York, in the autumn of 1902, and later Professor Holmes and Mr. Hrdlicka think it incredible that it can be of glacial age. Their opinion, however, is largely discounted by the fact that greatly exaggerated ideas of the antiquity of the glacial epoch are entertained by most of these experts. When the evidence is made to show that the date of the Iowan glacial episode did not close until about the time that the civilization of Egypt, Babylonia and Western Turkestan had attained a high degree of development, and that the cranial capacity had at that time in those regions reached that of the higher races of the present time, there would seem to be little dependence to be put upon *à priori* dicta adverse to the glacial age of the Lansing skull.

The remains of the Nebraska Loess-Man were discovered in the summer of 1906, by Mr. Robert F. Gilder, who soon after called in Mr. E. H. Barbour, Professor of Geology in the University of Nebraska to make more extended investigations and give an expert opinion as to the age of the deposit.

The locality of this discovery is in the township of Florence on the western loess bluffs of the Missouri River a few miles above Omaha. Here from ten to twenty feet of glacial drift rest-

ing on a stratum of carboniferous limestone, is overlaid by 150 feet of loess, making the elevation above the river 200 feet. Near the surface there were found many relics indicating recent interments. But at lower depths, reaching in some cases eleven and a half feet, bits of bone were found. Below a depth of five feet there was no evidence that the loess

FIG. 191—Section of Long's Hill, Nebraska. The man is pointing to the base of the loess resting upon 40 feet of till. (Courtesy of Records of the Past.)

had been disturbed subsequent to its deposition, since here the characteristic vertical lime tubes and concretions were everywhere present. Moreover the fragments of bones were widely scattered, only five or six fragments being found to a cubic yard, and some of these evidently were water worn. The prize specimen was that of a skull broken, disarticulate and

scattered over a space of twenty-five square feet, between four and five deep in the undisturbed loess. The walls of this were thick, measuring as much as three-eighths of an inch. Counting all the fragments, Professor Barbour estimates that there are probably ten or twelve individual skulls represented in this loess bone bed and that comparison shows them to be of the Neanderthal type, with thick cranial walls.*

We are bound to say, however, that the glacial age of these relics, like everything else of much moment in scientific discovery, has been disputed by high authorities. In this case it has been done by Professor B. Shimek,† an accomplished investigator of land shells. From study of these in the loess deposits of the region he has become an ardent advocate of the æolian hypothesis respecting the distribution of loess, and hence approaches the question with the bias of that theory. For a general discussion of the æolian hypothesis the reader is referred to the chapter on the Loess. It is sufficient to say here that it is hardly possible that so experienced an authority as Professor Barbour, and one so familiar with the loess of the region could be mistaken in the matter. His excavations were extensive, and most carefully made, and his conviction of the undisturbed character of the portion of the deposit in which the remains were found was unequivocal. Professor Shimek's judgment in the case is also greatly discounted by his equally positive, but certainly, erroneous opinion that the deposit in which the Lansing skeleton was found was clearly distinct from ordinary undisturbed loess, "evidently consisting of slumped material." In short there is no valid reason to doubt the glacial age of the loess in which the remains of the Nebraska man were found.

The relic described by Miss Owen is an implement of paleolithic type, chipped from a porphyritic pebble (probably

* "Nebraska Geological Survey," vol. ii, part 5, pp. 318-327; part 6, pp. 331-348. Also "Records of the Past," vol. VI, Feb. 1907, pp. 34-39.

† "Bulletin of Geological Society of America," vol. xix, pp. 243-254, 1908.

from the Black Hills, Dakota). The illustration speaks for itself. This was found projecting from the face of an old cut for a road through the loess in the northern part of the city of St. Joseph, Missouri. It was found not less than twenty

FIG. 192—Implement from Dug Hill. (Miss Owen).

feet below the surface where there could be no question concerning its undisturbed character. This is on the east side of the Missouri River, where the total depth of the loess is more than 100 feet.*

* "Records of the Past," October. 1907, pp. 289-292.

CHAPTER XXIV. (*Concluded*).

MAN AND THE LAVA BEDS OF THE PACIFIC COAST.

The occurrence of human relics in the auriferous gravels of California, where in some places they are capped with extensive lava overflows, though still a subject under hot discussion is too important and interesting to be passed over without a full detail of the facts. The connection of these facts with the glacial epoch, though inferential, is by no means uncertain: for, confessedly, the lava flows west of the Rocky Mountains, though commencing early in the tertiary period, have continued in great volume down to very recent times, some extensive eruptions having occurred in California and Idaho within the last two or three hundred years; while the remains of extinct animals found in the auriferous gravels are substantially the same as to be found in the glacial deposits of the eastern United States and Europe. At the same time the indications are clear that the glaciers of the Sierras in California and elsewhere extended greatly beyond their present limits down to a period of time separated from us by only a few centuries. Nor should the existence of unbelief, on the part of many, prevent a candid consideration of the facts, for it is pre-eminently a question of evidence such as is employed in all historical investigations, and so, open to challenge. But we are convinced, it is beset with difficulties no greater than pertains to all investigations of a similiar nature.

The incredulity prevailing concerning these facts will largely disappear upon consideration of the evidence of re-

cent activity of volcanic forces on the Pacific Coast, and of the recency of the disappearance of the glaciers from the mountains of the region. All competent observers have remarked the freshness of the lava deposits in the Snake river Valley in Idaho, while Mr. Diller* has shown that in the great interior basin in California near Lassen Peak, between Snag Lake and Lake Bidwell, there is a region many miles in extent covered with lava and volcanic ash to a uniform depth of many feet, with cones rising more than 600 feet, all of which must have been ejected within the last 200 years. Stumps of trees are still projecting from the stratum of volcanic ash which killed them, while the charred trunks of other trees which were overwhelmed by the lava stream still remain undecayed. It is impossible that these trunks could have resisted the corroding agencies even of this dry atmosphere for many centuries while none of the fresh trees growing on the surface of the stratum of volcanic ash are more that 200 years old.

It should be remembered also that the vast erosion since the auriferou gravels were covered by lava was hastened by the enormous floods which occurred when the glaciers which had been subsequently formed melted off. The floods arising from the annual melting of the snow in the region are now enormous. How much greater must they have been in the declining years of the Glacial Epoch!

The first evidence upon the point to which we will turn attention is that produced by Professor J. D. Whitney† of Harvard University, concerning human remains believed by him to have been found in strata which mark the closing period of the Tertiary epoch in California.

The following description of the deep placer deposits in which these remains have been found is given by Le Conte:

* See "Bulletin of U. S. Geol. Survey," No. 79, 1891.

† "Report on the Auriferous Gravels of the Sierra Nevada," 1879, p. 258 *et seq.*

There are in many parts of California two systems of river-beds, an *old* and a *new*. The old belongs to the Tertiary; the new, to the Quaternary and present. The change took place during the oscillations of the Quaternary. The old river-system is substantially parallel to the present river-system, though in some places the one cuts across the other. It is probable, therefore, that there was but little change in the general direction of the slope, produced by the oscillations of this epoch. These old river-beds are filled with drift-gravel, and often covered with lava-streams. These drift-gravels probably represent the beginning of the Glacial epoch, though Whitney thinks an earlier or Pliocene epoch. The present river-system sometimes cuts across, sometimes runs parallel to, the lava-filled beds of the old river-system, and the beds of the former have in their turn been eroded two thousand to three thousand feet in solid rock. In these also have been accumulated immense quantities of gravel and bowlder drift, evidently brought

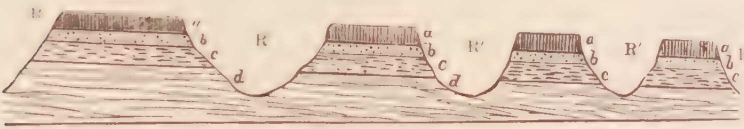

FIG. 193.—Lava-stream cut through by rivers; *a, a*, basalt; *b, b*, volcanic ashes; *c, c*, tertiary; *d, d*, cretaceous rocks; *R, R*, direction of the old river-bed; *R', R'*, sections of the present river-beds. (Le Conte from Whitney.)

down from the glacial moraines by the swollen rivers of the Champlain and early Terrace epochs. These facts are illustrated by Figs. 193 and 194, in which *R'* represents the present

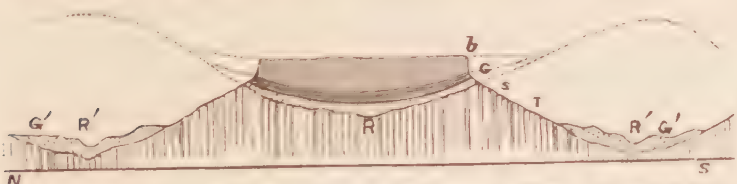

FIG. 194.—Section across Table Mountain, Tuolumne County, California: *b*, lava; *G*, gravel; *s*, slate; *R*, old river-bed; *R'*, present river-bed. (Le Conte.)

river-system, in Fig. 193, cutting across, and in Fig. 194 running parallel to, the old system *R*.

Although it is impossible to synchronize with certainty

these events with the changes in the eastern portion of the continent, yet the order of sequence is evident ; and that the greater part, if not all, occurred in the Quaternary, is also evident. . . .

The history of changes shown in these sections is sufficiently obvious. In the time of the old river-system, *R* was a river-bed, doubtless with a ridge on either side represented by the dotted lines. In this bed accumulated gravel, containing gold. Then came the lava-flow, which of course ran down the valley, displacing the river and covering up the gravels. The displaced rivers now ran on either side of the *resistant* lava, and cut out new valleys, two thousand feet deep, in the solid slate, leaving the old lava-covered river-beds and their auriferous gravels high up on a ridge. In other cases the convulsion which ejected the lava also changed greatly the general slope of the country, and therefore the direction of the streams. In such cases of course the present river-system cuts across the old river-beds and gravels, and their covering lavas, as shown in Fig. 142.

The age of the old river-gravels is still doubtful ; that of the newer river-gravels is undoubtedly Champlain or early Terrace. Below we give a list, taken from Whitney, of the remains found in these gravels :

Newer Placers.—Great mastodon, mammoth, bison, tapir (modern), horse (modern), man's works.

Deep Placers.—Great mastodon,* mammoth, tapir (modern), rhinoceros (ally), hippopotamus (ally), camel (ally), horse, extinct species.

It will be seen that the fauna of the deep placers unite Pliocene and Quaternary characters. The great mastodon, the mammoth, and the tapir, are distinctively Quaternary, while the others are Pliocene. The plants, according to Lesquereux, are decidedly Pliocene. Therefore Whitney has not only placed the deep placers in the Pliocene, but made them the representative of the whole Pliocene, and probably Miocene, and the lava-flow as the dividing-line between the Tertiary and the

* Whitney states that the mastodon is not found here, but it has been since found.

Quaternary. But, all the facts considered, it seems most probable that both the filling of the old river-beds, and their protection by lava, took place comparatively rapidly, and were together the closing scene of the Tertiary drama. The deep gravels, therefore, may be placed indifferently in the latest Pliocene or earliest Quaternary. The newer gravels are undoubtedly Quaternary aad recent. Certain it is that the deep placer-gravels are similar in all respects to the Quaternary gravels all over the world, except that, by percolating alkaline waters containing silica, they have been cemented in some cases into grits and conglomerates. This is because they are covered with lava which yields both the alkali and the soluble silica.

In any case, we have here an admirable illustration of the immensity of geological times. The whole work of cutting the hard slate-rock two thousand feet or more has been done since the lava-flow, and therefore certainly since the beginning of the Quaternary.*

It will readily be seen that these upper gravels, whether we call them Tertiary or Quaternary, are with reference to the historical period very ancient, though *recent* if spoken of from a geological point of view. The question of man's antiquity does not turn on the *name* of the formation; but upon the reality of the existence of his remains in the upper gravels. Indeed, there does not seem to be any hard-and-fast line of demarkation between the Tertiary formation and the Quaternary, or recent. In making chronological calculations from the vast amount of erosion spoken of in the preceding paragraph, Le Conte warns us, however, to note the prodigious rapidity with which erosion now proceeds in connection with hydraulic mining. "In the North Bloomfield mine, the pebble-loaded torrent resulting from the incessant play of the hydraulic jet against the cliff, though working but eight months per year, has cut in four years a channel three feet wide and fifty feet deep in solid slate." †

* Le Conte's "Elements of Geology," 1888, pp. 555, 585.

† "American Journal of Science," March, 1880, vol. cxix, p. 179.

Unfortunately, the evidence that human remains have been taken from beneath these lava-capped mountain-ridges is neither of recent date nor that of professed geologists. We are compelled to depend upon the testimony of plain miners, exhibiting what they found and recounting what they saw several years ago. This fact, which needs explanation, is said to arise from the wholesale changes in the methods of mining introduced by hydraulic processes. By present methods terraces are washed down into a promiscuous heap by jets of water forced against them with great velocity, so that there is little hope of finding the archæological specimens they may have contained. The golden days for the archæologist in California have passed by. Still, so many independent witnesses from different localities have testified to the facts which we now relate, and circumstantial evidence so fully corroborates the statements of the witnesses, that Professor Whitney and his associates think they are beyond question.*

As early as 1863 Dr. Snell, of Sonora, began a systematic collection of animal and human remains from the mines in his vicinity. In his collection were several objects marked as "From under Table Mountain," among which was a human jaw. Dr. Snell's collection was destroyed by fire, and he died in 1869; but Professor Whitney and Mr. Voy had repeatedly examined it and conversed with him. A stone utensil, apparently used for grinding, was the only one which Dr. Snell claims to have taken with his own hands from the dirt as it came out of the tunnel under the mountain.

In 1857 Hon. Paul Hubbs, of Vallejo, Cal. (subsequently a State Superintendent of Public Instruction), picked a portion of a human skull out of the dirt as it was brought from the Valentine shaft, under Table Mountain, near Shaw's Flat. This skull was given to Dr. C. F. Winslow, who soon after (October 7, 1857) divided it, and sent one piece to the Phila-

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* A few paragraphs are here substantially reproduced from my "Studies in Science and Religion," p. 285 *et seq.*

delphia Academy of Sciences and the other to the Boston Society of Natural History, where it still remains, and in whose "Proceedings" (vol. vi, p. 278) Mr. Winslow's original communication may be found.

Ten years after, Mr. Hubbs more fully detailed the circumstances of the discovery, and Professor Whitney and Gorham Blake, Esq., made special examination of the locality and careful inquiries of the owners of the mine, and satisfied themselves that the bone really came from under the basaltic covering of Table Mountain. Mr. Walton, one of the owners, did not remember anything about the bone, but did remember that a "mortar" had been found in the tunnel, near the same situation.

In 1870 Mr. Oliver W. Stevens gave to Mr. Voy a large stone bowl, which was incrusted with sulphuret of iron, and which he makes affidavit that he picked with his own hands, in 1853, from a load of dirt which came from a tunnel under Table Mountain, two hundred feet in, at Shaw's Flat.

Mr. Llewellyn Pierce also makes affidavit that a certain stone mortar which he gave to Mr. Voy was taken, in 1862, from under Table Mountain, eighteen hundred feet from the mouth of the tunnel.

All this is preliminary to the famous Calaveras skull, the facts about which are as follows:

In February, 1866, Mr. Mattison, one of the owners of a claim on Bald Mountain, near Altaville, says he took from a tunnel under the basaltic capping of the mountain an object which, on account of incrusted earthy and stony material, he thought at first to be the petrified root of a tree, but which he discovered to be a portion of a skull. He took it to Mr. Scribner, agent of the express company, who, after seeing the importance of the discovery, passed it over to Dr. William Jones of Murphy's, a physician of extensive practice and scientific tastes. Both these gentlemen were well known to Professor Whitney, and their veracity is vouched for by him. The skull was forwarded by Dr. Jones to the office of the State Survey on the following June (1866). Mr. Mat-

tison has been repeatedly interviewed, and his testimony is uniformly coherent and explicit, to the effect that he took the skull with his own hands from gravel underneath a capping of forty feet of black lava and in connection with driftwood. The appearance of the skull in every way corroborates his statement. The original incrustation shows that it was not taken from a cave. The late Dr. Wyman, of Harvard College, and Professor Whitney together carefully removed the incrustations from the skull. Fragments of bones and gravel and shells were so wedged into the cavities of the skull as to satisfy them that there could be no mistake as to the character of the situation in which it was found. Chemical analysis showed that organic matter was nearly absent, and the carbonate of lime had largely displaced the phosphate; i. e., it was in a fossilized condition.

In a visit to Sonora, California, and to Bald Mountain, where the Calaveras skull was discovered, I was so fortunate also myself as to run upon evidence of a previously unreported instance of the discovery of a stone mortar under Table Mountain. The mortar was found in October, 1887, by Mr. C. McTarnahan, the assistant surveyor of Tuolumne county. It was lying in the gravel reached by the Empire Tunnel, and about a mile west of the Valentine shaft mentioned on page 692. This tunnel had been excavated 758 feet before reaching the gravel, and the mortar was found 175 feet in a horizontal line from the edge of the Table Mountain basalt, and about 100 feet below the surface. The object was taken out and laid beside the mouth of the tunnel, and was given to Mrs. M. J. Darwin, of Santa Rosa, Cal., who has given it to me. The mortar is made from a bowlder of some eruptive rock, and is six and a half inches through; the hollow being about three and a half inches in diameter, and about three inches deep.

"This mortar is now in possession of the Western Reserve Historical Society of Cleveland Ohio. An account of the discovery was given to the Geological Society of America, at Washington, in 1891.

At the same meeting Mr. George F. Becker of the U. S. Geological Survey, presented the affidavit of Mr. John H.

Neale, a mining engineer of much experience and high reputation, to the effect that in 1877 while running the Montezuma tunnel into the gravel underlying the lava of Table Mountain, Tuolumne County, near Rawhide Gulch, and when 1,400 feet from the mouth of the tunnel and between 200 and 300 feet from the edge of the solid lava, he found several spear heads of some dark rock and nearly one foot in length, and, near by, two mortars and a pestle.

"Mr. Neale declares it utterly impossible that these relics can have reached the position in which they were found excepting at the time the gravel was deposited, and before the lava cap formed. There was not the slighest trace of any disturbance of the mass or of any natural fissure into it by which access could have been obtained either there or in the neighborhood."*

With regard to this evidence Mr. Becker justly remarked that the mining engineer is of all persons in the world best fitted to determine whether the gravel in such a tunnel had been disturbed, for the chief danger in such mining arises from penetrating old drifts. Therefore a geologist would rather trust an engineer's testimony in such a case than his own.

The only reason found by Mr. Sinclair (whose general criticisms will be given later) for doubting the facts as here stated arises from the circumstances that the mortar of andesite and the spear heads of obsidian are found in pre-volcanic gravels. But this objection overlooks the fact that there was extensive commerce between the aboriginal tribes, and that the outflows of lava were by no means contemporaneous in different parts of the Pacific coast. Obsidian, for example, is found in large quantities in the mounds of Ohio, two thousand (2000) miles from any original deposit of the material.

Another bit of evidence from the same vicinity was presented by Mr Becker at the same meeting of the Geological

* "Bulletin of Geological Society of America," vol. ii, p. 192.

Society. This was a broken pestle found by Mr. Clarence King and taken with his own hands from undisturbed gravel under Table Mountain in the vicinity of Tuttletown not far from Rawhide Gulch. As Mr. King was a geologist of the highest reputation this would seem to be convincing evidence. But it is suggested that he may not have given attention to the question whether there had not been secondary cementation of the gravel, so that this may possibly have been in a talus. It is, however, hardly to be supposed that so experienced a geologist as Mr. King would have failed to notice a point of so much importance.

As already remarked the fact that new discoveries do not continue to be made in the auriferous gravels is readily accounted for from the fact that the profitable mines where such relics would be likely to be found have been worked out, and hence such mining has ceased.

The gravels under Table Mountain have not yielded enough gold to pay for the mining, and hence have been abandoned, while hydraulic mining so mingles the *débris* washed down that the discovery of implements in place is practically out of the question. Still, important discoveries do now occur.

In "Science" for March 6, 1906, Mr. J. F. Kemp, of the U. S. Geological Survey, reported the discovery of mortars and pestles in the auriferous gravels at Waldo, Josephine County, Oregon. The discoveries which he reports were made in 1901 and 1902. The latter was brought out by the miners during the night shift from 58 feet below the surface, where it was embedded in "the blue cement gravel" of the "pay channel." So firmly was it embedded that they had to resort to picks to extricate it and "the bed or hole out of which they pulled it remained, showing its perfect mould. "In the morning," says Mr. W. J. Wimer, the manager (who carefully noted the facts), "it was still packed tightly to its very rim with blue cement gravel" which after being carefully picked out yielded several "large colors of gold." The mortar is about twelve inches

high by nine inches across, and is made of the hardest granite. Pestles were found in this deposit often enough to cause no surprise. In 1901 another mortar with some pestles had been found ten feet under the surface and about 300 yards from this in the same "pay dirt."*

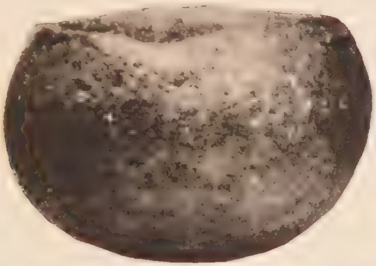

FIG. 195—McTarnahan Mortar from under Table Mountain

We omit mention of a large number of human remains found at great depths in the ancient higher-level gravel where not covered with lava, though some of them are doubtless of the same age with those from under Table Mountain.

According to Professor Whitney, the evidence "all points in one direction, and there has never been any attempt made to pass off on any member of the Survey anything out of keeping or, so to speak, out of harmony with what has been already found, or might be expected to be found. It has always been the same kind of implements which have been exhibited to us—namely, the coarsest and the least finished which one would suppose could be made, and still be implements at all." This result, he cogently remarks, would hardly be possible where so many parties are concerned in furnishing the evidence, if the objects were not genuine, and shows to his mind that the evidence has not been got up to deceive.

As might be expected, strenuous efforts have been made to discredit these facts. With reference to the Calaveras skull, we read in Dr. Southall's "Recent Origin of Man" (p. 558) that "Dr. Andrews informs us [Dr. Southall] that the Rev. R. W. Patterson, D. D., of Chicago, tells him that

* "Records of the Past" vol. v, June, 1906, pp. 190 191.

he was informed by the Rev. W. W. Brier, a reliable minister of Alvarado, Cal., that his [Brier's] brother, a miner, was one of two men who took the so-called Calaveras skull from a cave in the side of the valley, and placed it in the shaft, where it was found, and that the whole object was a practical joke to deceive Professor Whitney, the geologist." Whether this is probable can be judged from the foregoing statement of facts as since detailed by Professor Whitney. At any rate, it would have been the proper thing for this renegade brother of the Rev. Mr. Brier to have submitted himself to closer cross-examination from competent parties than he seems to have done.

Sir William Dawson and others have questioned whether these human remains might not have been introduced at a period subsequent to the deposition of the gravel and the overflow of the lava. They have suggested that the Indians, in searching for gold, may have run horizontal shafts into the gravel underneath; or, since the lava is not compact but tufaceous in its character, it does not seem impossible that, in some places, pits may have been sunk from the surface.

The most formidable opposition to Professor Whitney's conclusions comes, curiously enough, from evolutionists, so that, upon this question, they are now found "among the prophets." The thorough-going evolutionist believes that early man was ape-like in his features, and that he invariably passed through a stage in which he used rough stone implements before learning to polish them. But the Calaveras skull, which, if genuine, far antedates anything human which has been discovered in Europe, is not of a particularly inferior order, and the implements purporting to come from under Table Mountain are not of the palæolithic type, but, though exceedingly coarse and rude, correspond to those of the smooth stone period in Europe. Professor Putnam, however, suggests,* and Professor A. Winchell is ready to

* "Report of the United States Geological Surveys west of the One Hundredth Meridian," vol. vii, pp. 10–15.

admit,* that man wandered into California long before he entered Europe, and attained there the higher state of development reached by palæolithic man in other parts of the world at a much later date.

The objection to Professor Whitney's inferences arising from the possibility that the aboriginal inhabitants of that region themselves carried on mining operations for the sake of obtaining this gold is presented, in a convincing manner, by Dr. James Southall. According to him,† Bancroft, in his "Native Races of the Pacific States," refers to it as a well-known fact that mining operations were carried on in Mexico to a great extent, opening galleries into the solid rock, in some cases two hundred feet or more in depth; and Schoolcraft, in his "Archæology," ‡ describes one of these ancient shafts, which was discovered in 1849. This was two hundred and ten feet deep, and its mouth was situated on a high mountain. "The bones of a human skeleton were found at the bottom. There were also found an altar for worship and other evidences of ancient labor."

It is to be observed that, in the quotation from Schoolcraft made by Bancroft, it is stated that "no evidence has been discovered to denote the era of this ancient work. There has been nothing to determine whether it is to be regarded as the remains of the explorations of the first Spanish adventurers, or of a still earlier period. The occurrence of the remains of an altar looks like the period of Indian worship." Professor Putnam, however, writes me: "I think there is a strong objection to the ancient mining theory, inasmuch as we do not know of *gold* among the Californian Indians. The Mexicans had it, but did they mine it in California? The stone mortars we find in the California gravels are not of Mexican type, but of *Californian* type, the same form used in recent times."

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* "Pre-Adamites," p. 428. † "Pliocene Man in America," p. 7.

‡ Vol. i, p. 105. For a full summary of facts see Bancroft's "Native Races of the Pacific States," vol. iv.

A more serious arraignment of this whole evidence is made by Professor W. J. Sinclair of Berkely, California. It is unnecessary to review the whole of Mr. Sinclair's argument in detail. But in general it is sufficient to say that it is mainly occupied with throwing doubt upon the sufficiency of the evidence in each of the many individual cases of alleged discovery reported by Professor Whitney and others, but fails to break the force of the cumulative evidence arising from the great number of instances. For, it is highly improbable that so many cases each with so great probability would have been fabricated from such widely separated places. The theory of fraud in so many separate instances agreeing in the main point of contention yet differing so much in detail is exceedingly improbable. While the supposition that the gravels underneath the lava deposits had been previously worked over almost the whole area, is equally improbable.

But in particular it must be admitted that there has been a mistake in respect to the Caliveras skull reported to have been found by Mr. Mattison. The skull examined by Professors Whitney and Wyman and now in possession of the Peabody Museum of Harvard University evidently did not come from under the lava deposits described by Whitney as occurring at Bald Hill. For, Mr. Sinclair's examination of the skull and of the incrustation enveloping it shows that it must have come from some cavern in the vicinity used by the Indians as a sepulcher. Hence it follows that if Mr. Mattison actually took a skull from his drift under Bald Hill some other skull must have been substituted for it in the course of transmission. That this could have been done under the circumstances without impeaching the honor of any of the parties involved is readily seen from a fuller statement of some of the circumstances. Such, at any rate is the opinion of Professor Putnam. (See Sinclair's paper above quoted, p. 129). In confirmation, I may state that in 1890 when I visited Mr. Scribner he gave me the story substantially

as Professor Whitney relates it, but with some additional details bearing specially upon the points here raised though they had not been raised at that time. He said to me that when he gave the skull to Dr. Jones, soon after Mr. Mattison had given it to him, he was not able to furnish the particulars to the Doctor, as at the time he was not impressed with its importance. Dr. Jones, therefore, put it outside his office, with other collections of a similar sort, where it lay for several months until Mr. Mattison came to him one day for medical treatment, whereupon he asked him the particulars about the discovery of the skull, which he then for the first time learned.

This, therefore, makes it possible that while Mr. Mattison found a skull as he asserts he did and gave it to Mr. Scribner the wrong one was selected from Dr. Jones' pile, so that nothing is known now of the nature of the true skull or of the incrustation upon it. But that Mr. Scribner or Dr. Jones endeavored to impose upon Professor Whitney, is not credible from the known character of the men, and from their behavior in the whole matter; while there would have been no motive for any one to have imposed upon poor Mr. Mattison who was spending his last cent in vain efforts to find gold. And certainly, he made no effort to profit from the alleged discovery. It follows simply that we must drop out of the discussion everything that has been heretofore been said about the character of the skull. With that absent the discovery reported by Mr. Mattison becomes more easily credible than it was before.

A discovery in Idaho strongly confirmatory of those on the Pacific Coast is too important and interesting to be omitted.

In the autumn of 1889, Mr. Charles Francis Adams, then President of the Union Pacific Railroad, brought to my notice a small clay image, an inch and a half in length, which had been found by Mr. M. A. Kurtz while boring an artesian well at Nampa, Ada county, Idaho. The image was of slightly baked clay, incrusted in part with a coating of red oxide of

iron, which indicated considerable age, and came up in the sand-pump from a depth of three hundred and twenty feet. Near the surface the well penetrated a stratum of basalt, fifteen feet thick. Below this basalt there were alternate beds of clay and quicksand to the depth mentioned, where the sandstone rock was encountered. The well was tubed with heavy iron tubing six inches in diameter, so that there could be no mistake about the occurrence of the image at the depth stated. The detailed evidence was published by me in the "Proceedings of the Boston Society of Natural History" for January, 1890. During the following summer, I visited the locality and found ample confirmation of it.

It is proper also to be stated that Mr. G. M. Cumming, general manager of the Union Pacific lines in that district was on the ground the day the "find" was made, and carefully scanned the evidence, with the conclusion that there was no doubt of the facts as given. Probably no person in the world was better able than he to judge of the evidence. Later, other officials of the railroad who had interests in the vicinity took pains at my suggestion to re-examine the evidence with the result of confirming it in every respect. On the other hand, no one has come forward to challenge the evidence except on purely *à priori* grounds arising from preconceived opinions of the extreme antiquity of the deposits in which it is said to have been found. Close attention to the accompanying conditions will, however, I think modify these preconceptions.

In the valley between the Boisé and Snake Rivers, in southwestern Idaho, where Nampa is situated, there is an area of several hundred square miles covered with fresh-appearing basalt, which apparently came from vents thirty or forty miles to the east, but in its western flow barely extended five miles beyond Nampa. Below that point there is no lava for seventy miles. The clay and quicksand covering the stratum in which the image was found would seem to have accumulated in the valley of a stream having access to such an amount of sedimentary material that for a time it filled up rather than eroded its channel. Apparently the conditions favorable for such effects would

be most readily furnish during the Glacial period, when the streams of that region were swollen not only with the increased annual precipation, but with the melting of the glaciers which doubtless had for a long time occupied the mountains near the head-waters of the Boisé River to the north. Very likely, also, the lava-flows which obstructed the river a few miles above Boisé City turned its course to the southward, so that it may have wandered for some time over the plain in the vicinity of Nampa.

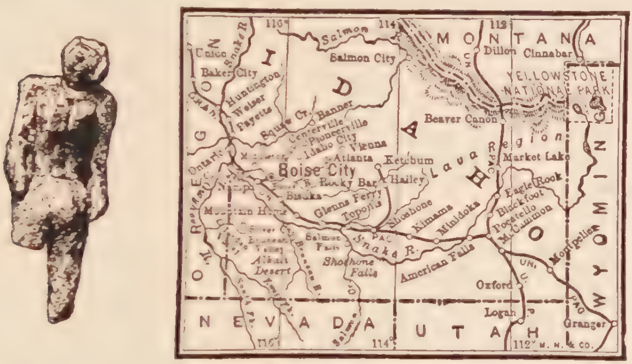

FIG. 196—Nampa figurine and map of the Snake river valley illustrating the text. For photograph of the bowlder bed at Pocatello described in the text, see page 615.

In addition to these general considerations we have here a most interesting and suggestive special situation from which much evidence may be derived in support of the foregoing interpretation of the facts. In the summer of 1890, while making investigations in the Snake River Valley at Pocatello, 350 miles above Nampa, and where the elevation is 2000 feet higher, I was confronted with an immense delta of bowlders, many of them three and four feet in diameter, at a considerable distance from the foot hills of the mountains to the south, which seemed inexplicable from any natural causes within

my knowledge. This delta of bowlders had been covered with a thin deposit of loam, and the city of Pocatello was built upon it. While I was there the city authorities were endeavoring to put in a sewer system, but were impeded by the general occurrence of these obstructing bowlders of great size. This bowlder bed is just where the Port Neuf River debouches upon the Snake River Plain. But upon going up the tributary valley a half mile or so the large bowlders ceased, and there was a scoured out channel free from them.

The explanation of this puzzling phenomenon was soon found in the result of Mr. Gilbert's investigations respecting the history of Lake Bonneville, to which reference has already been made. It was through the Port Neuf River that the great debacle from Lake Bonneville poured when the rising water surmounted the 1000-foot dirt barrier which retained the upper 350 feet of water over an area of 20,000 square miles. Mr. Gilbert estimates that it would require twenty years for a stream as large as Niagara to lower this body of water to the bottom of the dirt dam which was finally broken through, and that a stream as large as that did meanwhile pour through the opening leading to the Port Neuf, and so on into the Snake River Valley at Pocatello. Here, therefore, we have not only an adequate cause for the bowlder bed at Pocatello with all its peculiarities, but for the seemingly anomalous facts in the valley at Nampa 350 miles below, and at a level 2000 feet nearer that of the sea. The conditions were such as to favor the rapid accumulation of fine sediment which appears above the mouth of Boisé River, and above the great constriction of the channel which occurs a short distance beyond at Huntington, and continues for a long distance below.

Light is shed upon the geological date of this debacle by the fossils found at Glens Ferry, about half way between Pocatello and Nampa, and described by Dr. Dall. They are as follows: *Goniobasis taylori* Gabb (sp.), *Lithasia antiqua* Gabb,

Latia dalli White, *Sphoerium idahoensis* Meek, and *S. negosum* Meek.

These are found in consolidated gravel 100 feet beneath a thick capping of lava. The elevation of the lava here is 400 feet above that at Nampa, 85 miles farther down the river. According to Dall these sedimentary rocks belong to Cope's "Idaho Lake," and are "very likely middle or later pliocene. Both the unconsolidated character of the Nampa beds and the lower level at which they occur indicate a pleistocene age. They occur in a basin which has either been eroded out of Pliocene deposits synchronous with those at Glens Ferry, or in one formed by uneven elevations of land of which we have no definite record. The rapidity with which the deposits at Nampa were formed appears from their character. One of the beds of quicksand was 100 feet thick and two other 40 and 30 respectively. For 70 miles below Nampa there are no superficial lava beds, while there at the Oregon line, the Snake River Valley becomes very much constricted, and continues in a narrow gorge for a long distance. The situation furnishes just such conditions as would favor the rapid accumulation of fine sediment naturally brought down by such debacle from Lake Bonneville as is known to have taken place in pleistocene or glacial times. With respect to the age of the lava deposits it is also to be said that all observers, (especially Hayden and Russell) call frequent attention to outflows of lava in various parts of the Snake River Valley that are very recent—some of them not more than two or three centuries old. We, therefore, are amply justified in connecting the Nampa figurine with deposits of glacial age.

Conclusion. In the discoveries narrated above of man's relation to the glacial epoch the study of every class of glacial phenomena becomes invested with all the higher interest of historical research. Signal changes were introduced into the world's history by the conditions which accompanied the Glacial epoch. In America as well as in Europe this advent of northern cold greatly disturbed the conditions of animal life, and, we may well suppose, directly led to the extinction of many animal species. In North America the camel, the hippopotamus, the rhinoceros, the tapir, the mammoth, the horse, the mastodon, were abundant at the opening of the Quaternary age. Their complete extermination is one of the most startling facts in geology. But, as Darwin has so well shown, the effects of a glacial advance are by no means limited to the region directly reached by the ice. In pushing southward the plants and animals of the northern part of the continent, the struggle for life in the more crowded quarters of the decreasing congenial portions of the country became more and more intense, and thus doubtless was brought about much of the extinction of species which the geologists have to record as having taken place in the early part of the Quaternary period. The evidences of man's existence in North America before the close of the Glacial period would indicate that he too shared in the sharp struggle which ensued with the new and rapidly changing conditions of that time. Did he also, like so many of his companions among the larger animals, share in this extinction? The sharpness of the transition from the palæolithic to the neolithic type of implements, as we pass out from the Trenton gravel into the shallow soil above it, would seem to indicate an absolute distinction between the two succeeding races. But even so, whether the first became extinct from natural causes, and the other simply came in later as colonist, or whether the latter as conqueror exterminated the first, may always remain a doubtful question. It is possible that the Eskimo is the lineal descendant of preglacial man in America, and the conditions of life with which the Eskimo

is so passionately in love would seem to resemble closely those which evidently surrounded palæolithic man in New Jersey, Ohio, Indiana, and Minnesota. But, on the other hand, such human remains as we have from the Trenton gravel are regarded by Professor Putnam as belonging to a race distinct in type from the Eskimo.

A closing remark is in place with reference to the date of man's appearance in America. In the first place it should be observed that, to say man was here before the close of the Glacial period only fixes a minimum point as to his antiquity. How long he may have been here previous to that time must be determined by other considerations. Secondly, with our present knowledge of glacial phenomena, the date of the close of the Glacial period is regarded as much more modern than it was a few years ago. Sir Charles Lyell's estimate of thirty-five thousand years as the age of the Niagara gorge, which is one of the best measures of post-glacial time which has yet been studied, is greatly reduced by what we now know of the rate at which erosion is proceeding at the falls. Ten thousand years is now regarded as a *liberal* allowance for the age of that gorge. But, finally, the term "close of the Glacial period" is itself a very indefinite expression. The Glacial period was a great while in closing. The erosion of the Niagara gorge began at a time long subsequent to the deposit of the gravel at Trenton and at Madisonville. Between those two events time enough must have elapsed for the ice-front to have receded a hundred miles or more, or all the distance from New York to Albany; since only at that stage of retreat would the valley of the Mohawk have been freed from ice so as to allow the Niagara River to begin its work. The deposits at Trenton, Madisonville, and Medora, took place while the ice-sheet still lingered in the southern water-shed of New York and Ohio. When, therefore, the age of the mound-builders of Ohio is reckoned by centuries, that of the glacial man who chipped these palæolithic implements must be reckoned by thousands of years.

As is evident from the description of Mr. Upham, the

gravel at Little Falls, Minn., is considerably more recent than that in the more southern localities, since the gravel in Minnesota could have been deposited only when the ice-front had retreated some hundreds of miles from its farthest extension, while the first-named deposits occur near the very margin of the glaciated area.

Most of those who have taken pains to read the preceding pages through from the beginning have doubtless been surprised at the wide range of questions involved in the subject under discussion. The movement of ice itself brings up for consideration one of the most singular and obscure of physical problems. A wide field of investigation is still open to the physicist in determining how it is that brittleness and mobility can so unite in one substance as to produce the phenomena of motion observed in living glaciers. The majesty of the ice-movement, as brought to light in the study of the glaciated area in North America, is equaled only in the movement of the forces of astronomy, or in that of those which have elevated the mountain-ranges on the surface of the earth. Almost every human interest in the northern part of the United States and in British America is likewise seen to be profoundly affected by the ice-movement which we have been permitted to study. During the great Ice age the old lines of drainage were obliterated, and new lines established, crooked places were made straight, and rough places plain. The change in the river-courses produced by the obstruction of glacial deposits has given rise to the innumerable waterfalls where have grown up the flourishing manufacturing and commercial centers of New England and the interior. The Great Lakes are in the main the result of similar glacial obstruction. The vast internal commerce of the lake region avails itself of slack-water navigation resulting from the ice-movements of the Glacial age. The innumerable lakes of smaller size which adorn the surface of the northern part of the continent are also the result of glacial action. The anomalous distribution of insects and plants can likewise, in many cases, be traced to the same cause. The

arctic butterflies and the Alpine flowers upon the summit of Mount Washington, as well as the gigantic forests of California and some of their more distant relatives on the Atlantic coast, were fugitives from the arctic regions in glacial times, who have since become naturalized citizens of the lower latitudes. And, finally, man himself is connected with the closing centuries of the Glacial period in the United States. American scholars who are ambitious to carry on archaeological investigations need no longer go to the valley of the Euphrates or the Nile, or to the languages of central Asia, to find the oldest relics of man in the world, or the surest means of determining the greatness of his antiquity. A boundless, comparatively unworked, most promising and most interesting field lies before the American investigator in the glacial problems of his own country. Nowhere else in the world did the ice of the Glacial period deploy out upon so wide a margin of dry land, and leave so inviting and easy a field of study. Every river rising within the glacial boundary and emerging from the glaciated region presents a problem worthy of the life-long attention of any investigator. Every glacial waterfall and every glacial lake holds out the possibility of yielding up an important clew to chronological questions of absorbing interest. The ingenuity of Professor Asa Gray and others in tracing out the effects of the great Ice age upon the distribution of plants and animals, has only introduced us to subjects which need yet to be worked out in endless detail. The object of the present treatise will be largely accomplished if it serves to stimulate and guide the host of local investigators which the subject is sure to interest.

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